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NEMATODES INHABITING THE CYSTS OF THE SUGAR-BEET NEMATODE (HETERODERA SCHACHTII SCHMIDT)[1]

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INTRODUCTION

While examining the 38,128 cysts of *Heterodera schachtii* Schmidt used in studying its dormancy,[2] the writer found many cysts that contained other species of nema. In certain fields these species occurred so frequently that the possibility was suggested that they were feeding upon the eggs and larvae contained in the cysts.

METHODS

These cyst-inhabiting species were present in both fields where mononchs[3] were studied, and it was possible to secure data for both projects from the same series of soil samples. These samples were collected by the Cobb method,[4] in tubes having an area of one-millionth of an acre. Each sample examined was an aliquot part of two to six samples, usually two. The soil of each 2-inch depth was collected separately, care being exercised not to mix it with soil from above or below the specified depth. The samples were washed by the Cobb sifting and gravity method, and a determination was made of the nema present, both within the cysts and living free in the soil.

RESULTS OF SOIL EXAMINATIONS

The 1923 data contained in Tables 1, 2, and 3 for the field at Salem, Utah, are typical of those secured and, being the most complete, are presented here as representative of the generally existing conditions. Two species, *Cephalobus oxyuroides* de Man 1884 and *Acrobeles bütschlii* (*Acrobeloides*) (de Man) 1885 (fig. 1), predominated in the cysts.

Table 1 gives the number and distribution of the collected cysts of *Heterodera schachtii*. Of these 4,997 cysts examined, 1,021 contained an estimated total of 103,602 eggs and larvae. The remaining 3,976 were empty, the eggs having hatched and the larvae escaped into the soil. These empty cysts represent an accumulation of many years, for they are of a cutinous, almost indestructible material, and great numbers accumulate in the infested soil.

[1] Received for publication July 31, 1928; issued December, 1928.

[2] THORNE, G. LENGTH OF THE DORMANCY PERIOD OF THE SUGAR-BEET NEMATODE IN UTAH. U. S. Dept. Agr. Circ. 262, 5 p. 1923.

[3] THORNE, G. THE LIFE HISTORY, HABITS, AND ECONOMIC IMPORTANCE OF SOME MONONCHS. Jour. Agr. Research 34: 265–286, illus. 1927.

[4] COBB, N. A. ESTIMATING THE NEMA POPULATION OF SOIL, WITH SPECIAL REFERENCE TO THE SUGAR-BEET AND ROOT-GALL NEMAS, HETERODERA SCHACHTII SCHMIDT AND HETERODERA RADICICOLA (GREEF) MÜLLER, AND WITH A DESCRIPTION OF TYLENCHOLAIMUS AEQUALIS N. SP. U. S. Dept. Agr., Bur. Plant Indus., Off. Agr. Tech. Circ. 1, 48 p., illus. 1918.

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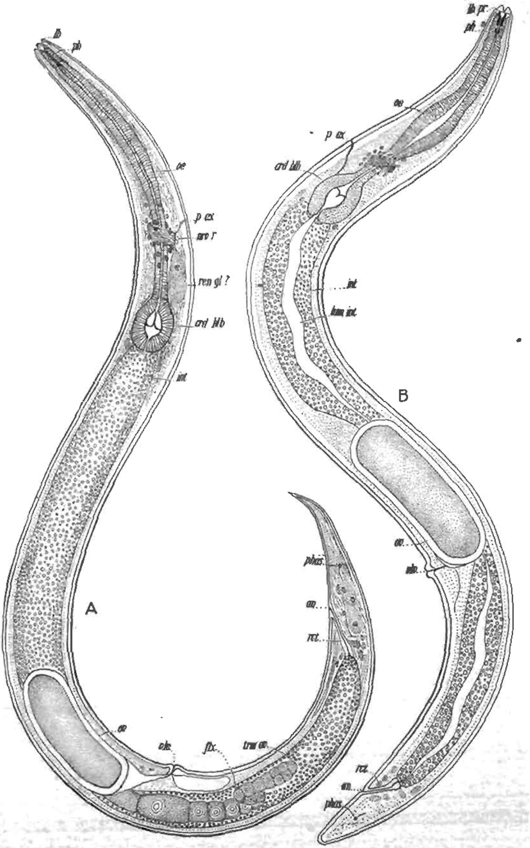

FIG. 1.—Adults of *Cephalobus oxyuroides* (A) and *Acrobeles bütschlii* (*Acrobeloides*) (B). × 450

Key: *an*, anus; *crd blb*, cardiac bulb; *flx*, flexure of ovary; *int*, intestine; *lb*, lip or labial projection; *lum*, lumen; *nrv r*, nerve ring; *oe*, esophagus; *ov*, ovum; *p ex*, excretory pore; *ph*, pharynx; *phas*, phasmids; *pr*, probolae; *rct*, rectum; *ren gl(?)*, renette gland; *trm*, terminus; *vlv*, vulva.

TABLE 1.—*Number and distribution of cysts of Heterodera schachtii at Salem, Utah, in 1923*

Depth in the soil	Date collected							
	June 23	June 30	July 12	July 20	Aug. 8	Aug. 29[a]	Sept. 5	Nov. 6
Inches	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1–2	128	36	389	34	27		50	131
3–4	61	58	240	80	57		133	146
5–6	58	27	162	113	35		210	144
7–8	16	17	100	35	82		112	107
9–10	88	20	78	139	121		153	223
11–12	68	46	40	37	56		74	167
13–14	17	52	7	9	22		87	219
15–16	3	36		4			69	208
17–18							41	49
19–20	4	4					25	23
21–22							11	9
23–24								
Total[b]	443	296	1,016	451	400		965	1,426

[a] Sample taken outside area infested by *Heterodera schachtii*.
[b] Grand total, 4,997; average population per acre, 624,375,000.

Table 2 shows the distribution of the 386 *Cephalobus oxyuroides* that were found in the samples. None of these was found living free in the soil. They were secured from 201 cysts, 70 of which contained eggs or larvae of *Heterodera schachtii*, and 131 were empty.

A comparison of Tables 1 and 2 shows two interesting facts: (1) On August 29 the sample was taken outside the area infested by *Heterodera schachtii*, and on that date no *Cephalobus oxyuroides* were collected; (2) in the samples collected September 5 and November 6, *H. schachtii* was found to a depth of 22 inches. On these same dates the many specimens of *C. oxyuroides* were found deep in the soil, indicating that at this season of the year they selected that point of habitat if their preferred food was present.

TABLE 2.—*Number and distribution of Cephalobus oxyuroides at Salem, Utah, in 1923*

Depth in the soil	Date collected							
	June 23	June 30	July 12	July 20	Aug. 8	Aug. 29[a]	Sept. 5	Nov. 6
(*Inches*)	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1–2				6				
3–4								
5–6			2					
7–8	2	2	8				4	
9–10		10	5		1			
11–12	12	41	9		10		17	
13–14	17	3	14		1			35
15–16	19	2					52	26
17–18							6	40
19–20							4	9
21–22							18	11
23–24								
Total[b]	50	58	38	6	12		101	121

[a] Sample taken outside area infested by *Heterodera schachtii*.
[b] Grand total, 386; average population per acre, 48,250,000.

Table 3 gives the distribution of 504 *Acrobeles (Acrobeloides) bütschlii* found in the samples. Of these, 384 were secured from 317 cysts and 120 were from the soil. Of the cysts inhabited by this species, 134 contained eggs or larvae and 183 were empty. The numbers occurring in a cyst varied from 1 to 11. Frequently an adult female was present with a number of progeny varying in size from those just hatched to some as large as the mother. This species is more generally distributed throughout the beet-growing regions of the

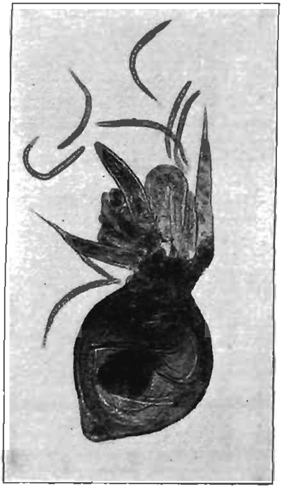

FIG. 2.—Photomicrograph of female *Heterodera schachtii* containing adults and young of *Cephalobus elongatus*. Apparently this was an unfertilized female and the Cephalobi had entered the body after its death; it was therefore not a case of true parasitism. × 70

Western States than *Cephalobus oxyuroides* and very frequently is found living free in the soil where *Heterodera schachtii* is not present. In this connection it will be noted that the sample collected August 29 contained 45 *A. bütschlii*, although *H. schachtii* was not present in that portion of the field. In many fields heavily infested with *H. schachtii* it is not unusual to find hundreds of *A. bütschlii* living free in the soil with rarely an individual present in the numerous cysts, indicating that preferred food is abundant outside the cysts.

TABLE 3.—*Number and distribution of Acrobeles (Acrobeloides) bütschlii at Salem, Utah, in 1923*

Depth in the soil	Date collected							
	June 23	June 30	July 12	July 20	Aug. 8	Aug. 29 [a]	Sept. 5	Nov. 6
(*Inches*)	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1–2	4			6				5
3–4			17	2		1		1
5–6	20	2	18	1		4		
7–8	8	4	47				5	
9–10	8		105	3	3	4		
11–12	73	3	40		7	36	3	
13–14	2	5	18		14		1	3
15–16		1					12	9
17–18				1			1	4
19–20							2	
21–22							1	
23–24								
Total [b]	115	15	245	13	24	45	25	22

[a] Sample taken outside area infested by *Heterodera schachtii*.
[b] Total number of cysts, 384; total number of free living, 120; grand total, 504; average population per acre, 63,000,000.

Other species of nematodes found in small numbers in the cysts of *Heterodera schachtii* from fields located in various parts of Utah, Idaho, Colorado, and California are as follows: *Acrobeles ankyrus* Thorne, *A. complexus* Thorne, *A. contractus* Thorne, *A. ctenocephalus* Thorne, *A. minimus* Thorne, *A. symmetricus* Thorne, *Cephalobus elongatus* de Man (fig. 2), *C. persegnis* Bastian, *C. striatus* Bastian, *Dorylaimus obtusicaudatus* Bast. (fig. 3), *Tylenchus* sp., and *Plectus* sp.

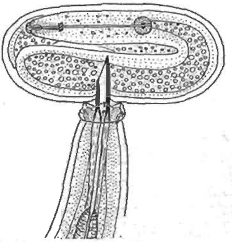

FIG. 3.—Sketch of the head of a young *Dorylaimus obtusicaudatus* with an egg of *Heterodera schachtii* impaled upon the spear. The young of this species are quite frequently found inhabiting the cysts of *H. schachtii*, but only three specimens have been seen with eggs impaled upon the spear. This species is not generally predacious, and these occurrences are probably accidental. × 350

ECONOMIC IMPORTANCE

Observations on the habits of many species of Acrobeles[5] and Cephalobus have led the writer to believe that primarily they are saprozoans. From the fact that eggs and larvae were present in only 41 per cent of the cysts inhabited by *Cephalobus oxyuroides* and *Acrobeles bütschlii*, it seems evident that they must have been feeding on the remnants of the internal organs of the female *Heterodera schachtii* and not on the eggs and larvae. Both of these species are too small to swallow an egg entire, and neither possesses a spear or teeth with which the eggs could be broken. Even if they were able to attack and devour the egg and larvae, the small percentage destroyed would cause no appreciable diminution in the population of *H. schachtii*. It will thus be apparent that these examinations fail to indicate that the nemas observed in Heterodera cysts are of economic importance in the control of this highly important sugar-beet pest.

[5] THORNE, G. THE GENUS ACROBELES VON LINSTOW, 1877. Amer. Micros. Soc. Trans. 44: 171–210 illus. 1925.

SEED-COAT STRUCTURE AND INHERITANCE OF SEED COLOR IN SORGHUMS [1]

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INTRODUCTION

Seed color is one of the most definite taxonomic characters of the sorghum plant, and it is also of considerable economic importance because of its influence on the market value of the grain. The mode of inheritance of kernel color, however, has been perplexing, and various Mendelian ratios have been obtained by plant breeders who have studied crosses of different sorghum varieties. Most of these genetic data have been obtained on the basis of surface examination and without considering the structure and pigmentation of the various layers of the seed coat. A genetic study of crosses between Red Amber and Freed sorgos and Standard feterita and their reciprocals is presented here. The interpretation of these is based on the microscopic study of the seed coats of the segregates and of several standard varieties of sorghum.

LITERATURE REVIEW

Graham [3] of India in 1916 classified the segregates from a number of crosses of juar (sorghum) and found in one cross plants having three seed colors distinguished as red (*RRYY*), yellow (*rrYY*), and white (*RRyy* or *rryy*). Taking the families in which all three colors occurred, he found a total of 340 red-seeded, 96 yellow-seeded, and 139 white-seeded plants, or a close approximation to a 9:3:4 ratio. He also found on crossing a number of whites with one pure yellow that the whites proved to be of at least two genotypes. One white-seeded plant crossed with yellow produced red-grained F_1 plants and another produced yellow-grained ones. This led to the assumption that some of the whites contained one of the necessary factors for red, which in the presence of the yellow factor led to the production of red color. Graham made no statement as to the location of pigments in the varieties under observation.

Vinall and Cron [4] studied a cross of feterita × Red Amber sorgo and its reciprocal, grown at Chillicothe, Tex., and obtained a ratio of 15 plants with pigmented seed to 1 with white seed. They as-

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[1] Received for publication Aug. 24, 1928; issued December, 1928. Certain phases of the study here reported were submitted in June, 1923, to the faculty of the graduate school of the University of Minnesota in partial fulfillment of the requirements for the degree of master of science. These have been supplemented by additional data.

[2] The writer takes this opportunity to acknowledge the aid of Dr. H. K. Hayes, professor of plant breeding, University of Minnesota, for valuable criticism and advice. Dr. J. H. Parker, of the Kansas State Agricultural College, has generously permitted the writer to use data collected jointly. Prof. W. E. Davis, of the Kansas Agricultural College, assisted materially in developing the microscopic technic necessary for studying the seed coats of sorghums.

[3] GRAHAM, R. J. D. POLLINATION AND CROSS-FERTILIZATION IN THE JUAR PLANT (ANDROPOGON SORGHUM, BROT.). India Dept. Agr. Mem., Bot. Ser. 8: [201]–215, illus. 1916.

[4] VINALL, H. N., and CRON, A. B. IMPROVEMENT OF SORGHUMS BY HYBRIDIZATION. Jour. Heredity 12: 435–[443], illus. 1921.

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sumed the factors for color to be *R* (red) and *B* (brown), either one of which alone or in combination produced color, while the recessive condition for both *R* and *B* resulted in the production of white seed.

Sieglinger[5] in the cross Sunrise kafir × feterita and its reciprocal obtained a dihybrid ratio of 9 plants with brown seeds and brown nucellar layer, 3 with chalky-white seeds and brown nucellar layer, and 4 with glossy-white seeds and no brown nucellar layer. To explain this inheritance Sieglinger assumed the following factors:

B, a factor for brown nucellar layer which also may cause brown in the epidermis if *S* is present. Its allelomorph *b*, gives kernels without a brown nucellar layer.

S, a factor for smooth or glossy pericarp. When *S* is present the pericarp is glossy and may be creamy white, as in white kafir, or may carry other colors. Its allelomorph *s*, gives a chalky-white pericarp. Brown does not appear in the pericarp of an *ss* plant.

The results expected in the F_2 generation, from an independent recombination of the two factors just designated, would produce three phenotypes, classified as follows:

Brown seeded, with brown nucellar layer	Chalky white seeded, with brown nucellar layer	Glossy white seeded, with no brown nucellar layer
1 *BBSS* 2 *BBSs* 2 *BbSS* 4 *BbSs*	1 *BBss* 2 *Bbss*	1 *bbSS* 2 *bbSs* 1 *bbss* [a]
9	3	4

[a] Sieglinger recognized that this phenotype had a chalky-white seed coat, but he was not able to distinguish it from the other individuals of this group because of the discoloration of this seed from weathering.

By testing the progeny of F_2 heads in the F_3 generation, Sieglinger[6] was able to substantiate the above factorial constitution. He obtained like results in the cross Sunrise kafir × Blackhull kaoliang and assumed that the latter variety had the same seed characteristics as feterita. In the cross Sunrise kafir × Red kafir, Sieglinger obtained a ratio of three plants with red seed to one plant with white seed. No nucellar layer with pigmentation was present in either the Sunrise or Red kafir parents, so that the pericarp color differed by only one factor. The factors influencing color in the Sunrise and Red kafir cross were designated as *rr* for Sunrise kafir and *RR* for Red kafir. The *S* factor supposedly is present in both parents, and the red color of the F_1 was considered due to the combination *Rr*. Segregation in the F_2 generation gave the monohybrid ratio of three red to one white. A similar result was obtained from the cross White kafir × Red kafir. As would be expected in the cross between the two white-seeded varieties, White kafir and Sunrise kafir, no plants with colored seed were obtained.

Sieglinger[6] also determined the inheritance of three color factors in the cross Standard feterita × Red kafir. As noted above, Red kafir differs from Sunrise kafir in that it has a colored pericarp, both

[5] SIEGLINGER, J. B. SEED-COLOR INHERITANCE IN CERTAIN GRAIN-SORGHUM CROSSES. Jour. Agr. Research 27: 53–64. 1924.

[6] SIEGLINGER, J. B. Op. cit.

lacking the nucellar layer with its accompanying pigmentation. Sieglinger designated the genetic color make-up of feterita as *BBssrr*, and that for Red kafir as *bbSSRR*. The effects of the *Bb*, *Ss*, and *Rr* factors were the same as in the previously noted crosses, the presence of either the *S* or the *R* factor causing the brown color to appear in the epidermis of the seed. On a basis of three color factors the segregation in the F_2 generation should give 45 plants with brown seeds and brown nucellar layer, 3 with white seeds and brown nucellar layer, 12 with red or light-red seeds and no brown nucellar layer, and 4 with white seeds and without a brown nucellar layer. The observed ratios were in close agreement with this calculated distribution.

Conner and Karper[8] obtained a ratio of three plants with colored grain to one with white in a cross between Dwarf White milo and Dwarf Yellow milo. These investigators also obtained a segregation of 1 plant with red kernels, 2 with pale-red kernels, and 1 with white kernels in a cross between Blackhull White kafir and Red kafir, or a ratio of 3 colored to 1 white. Similar results were obtained from a cross of Blackhull White kafir × Pink kafir, except that the colored seed was designated as "pink" and "pale pink" in the F_2 generation. Representative types of homozygous pink, heterozygous pink, and homozygous white from the F_2 generation were grown in the F_3 generation and the correctness of the 1 : 2 : 1 segregation was substantiated. The F_4 progeny from 72 heterozygous individuals of the F_3 generation did not, however, give a very close approximation to the expected 3 : 1 ratio, the observed numbers being 3,163 colored and 1,477 white. The authors state: "This is evidently a poor fit for the classes, for reasons not known at this time, except for lack of proper determination of classes."

From the above review it is apparent that the inheritance of grain color in sorghums is complex and has not been worked out definitely. The writer believes, however, that a knowledge of the structure of the seed coat and the location of pigmentation offers a correct basis for interpreting data on the inheritance of seed color. The writer proposes some slight modifications of Sieglinger's hypothesis as to the effects of the several factors influencing the inheritance of color. It is believed that the modification, which is based on studies of seed structure, is substantiated both by the data of others just cited and by additional data presented in this paper.

INVESTIGATIONS

SEED COATS OF SORGHUMS

The sorghum kernel is a caryopsis. The pericarp, derived from the wall of the ovary, consists of epidermis, hypoderm, mesocarp, and cross and tube cells. Winton[9] found that the grains of some varieties of sorghum possess a nucellar layer, while in other varieties this layer is absent. The writer's observations agree with this conclusion. The nucellar layer is sometimes referred to as the hyaline layer. Morphologically it is derived from the nucellus. In some

[8] CONNER, A. B., and KARPER, R. E. THE INHERITANCE OF SEED COAT COLOR IN CERTAIN CROSSES IN GRAIN SORGHUM. Jour. Amer. Soc. Agron. 15: 338–344. 1923.

[9] WINTON, A. L. THE ANATOMY OF THE FRUIT OF CERTAIN CULTIVATED SORGHUMS. Conn. State Agr. Expt. Sta. Ann. Rpt. (1902) 26: 326–338, illus. 1903.

varieties of sorghum the developing endosperm completely absorbs the nucellus, while in others a layer of cells derived from the nucellus remains. Immediately under the nucellar layer is the aleurone layer, a part of the endosperm.

The color relationships of the different structures of the seed coat in the sorghum varieties studied by the writer were very definite. The nucellar layer when present contained a reddish brown pigment in all of the varieties studied. Color due to this pigmentation will be designated nucellar color.

The mesocarp is a starchy structure. When it is thick it obscures the color of the nucellar layer. If it is vestigial in development, the pigment in the nucellar cells is visible in varying degrees of intensity through the more or less corneous epidermal and hypodermal cells of the pericarp. Careful examination revealed no definite areas of pigmentation in the mesocarp itself. In a very few specimens small irregular areas appeared slightly colored as if the pigment had diffused from the nucellar layer into the adjacent starchy cells of the mesocarp. These colored mesocarp cells did not appear as compactly arranged as others in this structure. From this study it is at least safe to conclude that the starchy cells of the mesocarp carry pigments but rarely, and then only in very small irregular areas. In the seeds of two crosses of Pink kafir × feterita the mesocarp was found to be entirely missing, although the nucellar layer was present.[10]

The epidermal and the hypodermal cells of the pericarp are the carriers of pigmentation when color is found in the outer portion of the seed coat. In this paper such coloration is termed "pericarp color." Whether this pigment is of the same origin as that found in the nucellar layer was not determined by the writer. An intensely colored pericarp seems to be associated with a vestigial mesocarp and a pigmented nucellar layer.

The seed-coat structures of five varieties of sorghum are shown diagrammatically in Figure 1. Feterita has a chalky-white seed. It has a well-developed nucellar layer, but the color is obscured by the thick, highly developed mesocarp. The pericarp is colorless. Red Amber sorgo has a well-developed nucellar layer, a thin mesocarp (about 10 μ in thickness), and a reddish brown pericarp. Blackhull kafir has a colorless pericarp and no nucellar layer except for slight traces that are believed to be responsible for the colored specks in the seed coat. Yellow milo lacks the nucellar layer and has a poorly developed mesocarp. It has a salmon-yellow pericarp. Both Freed sorgo and White milo have poorly developed mesocarps and lack nucellar layers. Both lack pericarp color.

Relation of Seed-Coat Structure to Genetic Factors

The relation of the seed-coat structures to the genetic factors that control color inheritance is assumed by the writer to be as follows:

The factor *B* determines the presence of the pigmented nucellar layer and also is considered responsible for the development of the traces of nucellar color that may pass into the mesocarp or even into the pericarp if the mesocarp is poorly developed. *S* is a dominant factor, the presence of which causes a vestigial or poorly developed

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[10] The seeds of these crosses were supplied by J. B. Sieglinger, Office of Cereal Crops and Diseases, and R. E. Getty, Office of Forage Crops, Bureau of Plant Industry, U. S. Department of Agriculture.

mesocarp. The recessive allelomorph *s* determines a well-developed, starchy, opaque mesocarp, the presence of which inhibits even a slight expression of nucellar coloration, due to *B*, in the epidermal and hypodermal cells. When *R* is present, color is produced in the epidermal and hypodermal cells. When *B* and *R* are both present together with *S*, the factor for a poorly developed mesocarp, the effect is an intense coloration.

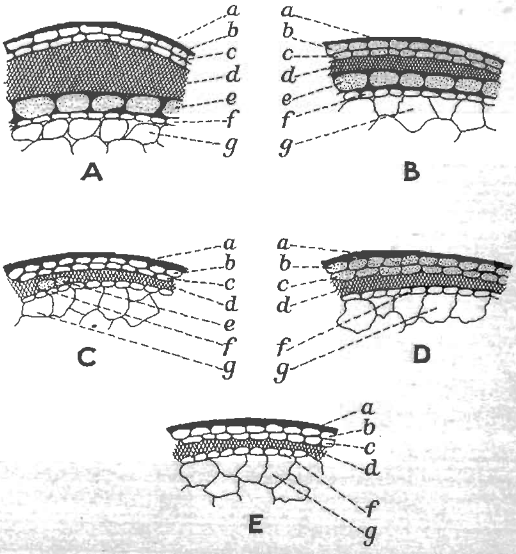

FIG. 1.—Diagrammatic sections of the seed coats of five sorghum varieties: *a*, Cuticle; *b*, epidermis; *c*, hypoderm; *d*, mesocarp; *e*, nucellar layer; *f*, aleurone layer; *g*, endosperm. A, Feterita; colorless epidermis and hypoderm, highly developed mesocarp, and nucellar layer; B, Red Amber; colored epidermis and hypoderm, thin mesocarp, nucellar layer; C, Blackhull kafir; colorless epidermis and hypoderm, thin mesocarp, and nucellar layer absent except for slight remnants; D, Yellow milo; colored epidermis and hypoderm, thin mesocarp, nucellar layer absent; E, Freed sorgo and White milo; colorless epidermis and hypoderm, thin mesocarp, nucellar layer absent

It is assumed that there are two classes of white seed, namely, pseudowhite and true white. The pseudowhites (*BBssrr* and *Bbssrr*) are so designated since the nucellar color factor *B* is present while the pericarp color factor *R* is absent. When *B* is present there is color in the nucellar layer, but it is masked by the well-developed mesocarp due to *s*. The true whites have the factorial constitution *bbssrr*, *bbSsrr*, or *bbSSrr* and are true whites because of the absence of both the pigmented nucellar layer and pericarp color.

The pseudowhites can usually be distinguished by removing the pericarp with a penknife to ascertain whether or not the colored nucellar layer is present.

Because of the nucellar layer, varieties of the pseudowhite group when crossed with other varieties may give coloration in progenies, depending on relative mesocarp thickness. When two varieties of true-white factorial constitution are crossed, only white-seeded progenies can be obtained. The pericarp of sorghums of the factorial constitution *BBSSrr*, *BBSsrr*, *BbSSrr*, and *BbSsrr* may possess some slight degree of coloration even though the pericarp color factor *R* is absent. How this slight pigmentation in the epidermal and hypodermal cells may occur is not clear, but in observed cases it was noted that the phenomenon was associated with a relatively thin mesocarp 35 μ to 50 μ in thickness. With a mesocarp of this thickness the nucellar color factor *B* apparently produces some pericarp color.

Data on seed-coat structure, the suggested genotype color factor constitution, and the actual seed color of the more important sorghum varieties are given in Table 1.

TABLE 1.—*Thickness of the various seed-coat structures, pigment location, superficial seed color, and possible color factorial constitution of representative sorghum varieties*

Sorghum variety	Thickness in microns of—				Location of pigment	Possible factors for color inheritance [a]	Notes
	Pericarp, including nucellar layer if present	Nucellar layer only	Pericarp				
			Mesocarp only	Epidermis, hypoderm, and cuticle			
Feterita	140	55	70	15	Nucellar	*Bsr*	*Chalky-white pericarp.*
Dwarf hegari	140	56	77	7	do	*Bsr*	Colorless pericarp with small reddish specks.
Manchu brown kaoliang.	140	35	70	35	Nucellar / Pericarp	*BsR*	Walnut-brown pericarp.
Red Amber	110	60	10	40	do	*BSR*	Reddish brown pericarp.
Broomcorn	95	45	10	40	do	*BSR*	Amber to walnut-brown pericarp.
Kansas Orange	85	25	25	35	do	*BSR*	Walnut-brown pericarp.
Darso	80	30	28	22	do	*BSR*	Do.
Schrock	125	45	50	30	do	*BSR*	Do.
Sudan grass	30	15	Trace.	15	do	*BSR*	Chocolate-brown pericarp.
Pink kafir	78	3	50	25	do	*BSr*	Colorless pericarp with pinkish specks or blotches. See text regarding nucellar layer.
Dawn kafir (Dwarf Blackhull).	70	Absent.	40	30	Absent	*bSr*	Colorless pericarp with small *reddish brown specks or* blotches.
Sunrise kafir	80	Absent.	45	35	do	*bSr*	Do.
Reed kafir	75	Absent.	45	30	do	*bSr*	Do.
Red kafir	45	Absent.	20	25	Pericarp	*bSR*	English red pericarp.
Freed sorgo	65	Absent.	30	35	Absent	*bSr*	Colorless pericarp.
Shallu	50	Absent.	10	40	do	*bSr*	Do.
Yellow milo	65	*Absent.*	45	20	Pericarp	*bSR*	*Ochraceous-salmon yellow pericarp.*
White milo	75	Absent.	40	35	Absent	*bSr*	Colorless pericarp.

[a] *B*, a dominant factor for pigmented nucellar layer, and *b*, its allelomorph for absence of nucellar layer and color; *S*, a factor for vestigial mesocarp, and *s*, its allelomorph for a heavy, starchy, opaque mesocarp; *R*, a *dominant factor for color in the* epidermal and hypodermal cells of the pericarp, and *r*, its allelomorph for lack of color in this region.

GENETIC DATA

Red Amber Sorgo × Feterita

The original Red Amber sorgo × feterita cross, with its reciprocal, was made in 1917, and the F_2 generation was grown by the writer in 1919, long before the seed-coat study reported above was made. In the F_2 generation the color intensities of segregates ranged from deep mahogany red or brown to white. Without a knowledge of the structure of the seed coat and the location of pigmentation it was difficult to classify the various colors properly. In this cross both parents possess a highly developed pigmented nucellar layer. The Red Amber sorgo differs from the feterita in that it possesses a pigmented pericarp with a poorly developed or vestigial type of mesocarp. The feterita has no pericarp color, but it has a highly developed starchy, opaque mesocarp that completely masks the pigmented nucellar layer.

The factors for seed color in line with Sieglinger's[11] findings may be designated in Red Amber as *BBSSRR*, and for feterita as *BBssrr*. The varieties, therefore, differ by the two factors *S* and *r*. The F_1 factorial constitution may be designated as *SsRr*. The 1,352 F_2 plants were classified as shown in Table 2.

TABLE 2.—*Segregation for seed color and suggested factorial constitution in the F_2 generation of the cross Red Amber sorgo × feterita grown at Hays, Kans., in 1919*

Item	Number of plants having—				Total number of plants
	Dark and light brown seeds	Buff seeds	Light buff, cream,[a] and pseudo-white seeds (with nucellar layer)	*True white seeds*	
Observed	771.0	260.0	321.0	None.	1,352
Calculated	*760.5*	*253.5*	*338.0*	*None.*	*1,352*
Deviation	10.5	6.5	17		
Factorial constitution	1 *SSRR* 2 *SsRR* 2 *SSRr* 4 *SsRr*	1 *ssRR* 2 *ssRr*	1 *SSrr* 2 *Ssrr* 1 *ssrr*		
Ratio[b]	*9*	*3*	*4*		

[a] The slight coloration in this group is believed to be due to nucellar pigmentation.
[b] $\chi^2 = 1.1667$; $P = 0.5667$.

No true whites would be expected in this cross, since both parents possess the pigmented nucellar layer. When the original classification was made in 1919, seeds with a slight tint of buff or cream color were placed in the true-white group. This was, of course, incorrect, as will be shown in the analysis of the reciprocal cross feterita × Red Amber sorgo made at a later date. Only 1 individual (*ssrr*) out of 16 would be expected to have the pseudowhite seed color of the feterita parent. That this was correct was shown by segregation in the reciprocal cross feterita × Red Amber sorgo, as shown in Table 3.

[11] SIEGLINGER, J. B. Op. cit.

TABLE 3.—*Segregation for seed color in the F_2 generation of the cross feterita × Red Amber sorgo, grown at Hays, Kans., in 1919*

Item	Number of plants having—			Total number of plants
	Colored seeds	Pseudo-white seeds	True white seeds	
Observed	1,016	74	None.	1,090
Calculated (15 : 1)	1,022	68	None.	1,090
Deviation	6±7.99	6±7.99		

Microscopic examination was made of the seed coats of kernels of the several phenotypes of the Red Amber × feterita cross and of the parents. The relation of the mesocarp thickness to color in the several phenotypes, all of which possess the nucellar layer, is shown as follows:

Phenotype	Thickness of mesocarp (μ)	Phenotype	Thickness of mesocarp (μ)
Red Amber sorgo parent	10	Buff	45
Feterita	70	Light brown	45
Pseudowhite	70	Dark brown	25
Light buff	40		

Classification for the reciprocal cross was more exact than for the original cross in 1919. On the basis of this more exact separation there were 15 plants with colored seeds to 1 plant with pseudowhite seeds. Since the microscopic examination of the seed coats of the different phenotypes possessing a nucellar layer showed that the pseudowhite color of feterita is due to a well-developed starchy mesocarp, the genetic data show that such a mesocarp is inherited as a recessive character.

The observed number of plants having pseudowhite seeds very closely approximated the theoretical number. As previously pointed out, no true whites could be expected in this cross. These data confirm those of Vinall and Cron[12] for the same crosses. These workers state that difficulty was experienced in properly classifying the colored heads.

The F_3 generation of the Red Amber sorgo × feterita progeny was grown and classified for color segregation. The F_2 seed had been inoculated with spores of kernel smut in order to study the inheritance of smut resistance, and as a result many of the heads were destroyed. This reduced the number available for color classification. Some of the F_2 heads that had been classified as white produced slightly colored seed in the F_3 generation. Likewise some F_2 heads that had been classified as browns and buffs produced a small proportion of whites in the F_3 generation, as would be expected from the segregation of heterozygous material. (Table 4.)

[12] VINALL, H. N., and CRON, A. B. Op. cit.

TABLE 4.—*Expected F_3 breeding behavior of the cross Red Amber sorgo × feterita*

F_2 phenotype and frequency	Genotype frequency	Genotype	Expected F_3 breeding behavior
9 brown	1	*SSRR*	Brown (intensely colored), breeding true.
	2	*SsRR*	3 brown, 1 buff.
	2	*SSRr*	3 brown, 1 light buff.
	4	*SsRr*	9 brown, 3 buff, 3 light buff or cream, and 1 pseudowhite.
3 buff	1	*ssRR*	Buff, breeding true.
	2	*ssRr*	3 buff, 1 pseudowhite.
3 light buff and cream	1	*SSrr*	Light buff, breeding true.
	2	*Ssrr*	3 light buff or cream, 1 pseudowhite.
1 pseudowhite	1	*ssrr*	Pseudowhite, breeding true.

The color of kernels classified as light buff, salmon, pinkish, and cream is believed to be due to the presence of both the nucellar factor *B* and the *S* factor for the thin mesocarp.

FREED SORGO × FETERITA

The F_2 generation of a cross between Freed sorgo and feterita was grown at the Hays station in 1926. The seeds of this cross were classified in the field during the fall of 1926 before a study had been made of pigment location. Seed colors fell into three phenotypes, none of which was highly colored. The most intensely colored seeds observed were described as light buff, others as buff white and a third group as white. An interesting feature of the buff-white group was the fact that the lower two-thirds of the seed, which was protected by the glumes, was white. The outer or upper end of the seed, which was more exposed to sunlight, was buff in color.

TABLE 5.—*Segregation for seed color and suggested factorial constitution in the F_2 generation of the cross Freed sorgo × feterita grown at Hays, Kans., in 1926*

Item	Number of plants having— Light buff seeds	Buff white seeds	Pseudo-white seeds (with nucellar layer)	True white seeds (without nucellar layer)	Total number of plants
Observed	235	168		301	704
Calculated	220	176	132	176	704
Deviation	15	8			
Factorial constitution	1 *BBss* 2 *BBSs* 2 *BbSS*	4 *BbSs*	2 *Bbss* 1 *BBss*	1 *bbss* 2 *bbSs* 1 *bbSS*	
Ratio [a]	5	4	3	4	

[a] The plants having pseudowhite and white seeds were grouped together and the values for χ^2 (=1.5454) and P (=0.4764) determined on the basis of a 5:4:7 ratio.

As shown in Table 5, a Freed sorgo seed is without a nucellar layer or pigmentation in any region, and it has a thin mesocarp. The only source of coloration in either parent of the cross is the highly colored nucellar layer of the feterita parent. In feterita this coloration is obscured by a well-developed mesocarp. The nucellar layer

in the absence of a well-developed mesocarp and of pericarp color may cause seed colors ranging from light buff or pink to cream.

The genetic factors for seed color in the Freed sorgo are designated as *bbSSrr* and for feterita *BBssrr*. The recessive factor *r* is common to both parents. As shown in Table 5, the segregation in the F_2 generation for the two remaining factors was in the simple dihybrid ratio of nine plants with colored seeds to seven plants with white seeds. The observed segregation was in accord with the theoretical.

DISCUSSION

It frequently has been stated that normal characters are the result of the interaction of many factors plus environment. The effect of such interaction is strikingly demonstrated in the case of the three factors (*B*, *S*, and *R*) responsible for the inheritance of color in the seed of sorghum. When all three factors are present the pericarp is intensely colored. If the nucellar layer is present in combination with a highly developed mesocarp the nucellar color is invisible. To this extent a thick mesocarp functions as a color inhibitor. A very thin mesocarp makes it possible for nucellar pigmentation to be observed through the pericarp, and there is some indication of slight pigmentation in the pericarp itself even when the pericarp color factor is absent. The mesocarp was entirely absent in a few specimens examined.

The data indicate that mesocarp development is dependent on a single main pair of factors. A highly developed thick mesocarp is a recessive character. The extent of mesocarp development is somewhat variable, but whether this variation is the result of environmental influences or modifying genetic factors is not known. The extent to which environment might influence the expression of seed color in sorghums is apparent from even casual observation. For instance, in a year of extreme drought mesocarp development might easily be less than in a year of sufficient moisture. Such a reaction would have a direct influence on the intensity of seed color in so far as this is determined by mesocarp thickness.

Whether the pigment found in the nucellar layer is of the same chemical origin as that found in the epidermal and hypodermal cells in the pericarp was not determined. Genetically two different factors are responsible for the development of color in the two regions, one acting in the nucellar layer and the other in the pericarp. The data from crosses in which the pigment was located in the nucellar region seem to indicate that slight pigmentation also occurred in the pericarp of progenies in which the mesocarp was relatively thin. This would indicate at least some slight effect of the *B* factor on the epidermal and hypodermal cells of the pericarp when a thick mesocarp is not present to act as an inhibitor. That the two color factors are distinct is shown, however, when a sorghum such as Yellow milo with a colored pericarp is crossed with a variety lacking pigmentation in any region. In such cases seed color is inherited in a monohybrid ratio.

Reference has been made in Table 1 to certain varieties of kafir and Dwarf hegari that are white or colorless with small reddish brown specks or blotches. These specks are a definite varietal characteristic. Microscopic examination of Blackhull White kafir seed in

areas where the specks occurred showed small but scattered remnants of pigmented nucellar cells. In sections taken a little to one side of the specks there were no nucellar cells. It was also noted that the starchy mesocarp cells were very poorly developed just above the nucellar remnants, so that the coloration of the remnant groups was highly apparent.

Dwarf hegari has a fully developed nucellar layer, but the seed coat is more or less specked. In this variety the mesocarp was more poorly developed in the areas where the specks occurred than in sections taken a little to one side of the coloration.

A peculiar condition was found in some strains of Pink kafir in that a faint remnant of the nucellar cell walls surrounded the entire endosperm. The thickness of this remnant wall averaged approximately 3 μ, while the thickness of the nucellar layer in most varieties measured from 25 μ to 50 μ. The seed coat of Pink kafir is colorless except for pinkish specks or blotches. These specks apparently are due to isolated groups of nucellar cells overlaid by a thin mesocarp similar to those occurring in the white-seeded kafirs.

The inheritance of specks on the seed coat has not been determined.

The writer was not able to determine any relation of the aleurone layer or the endosperm to color development in sorghum. The cells of the aleurone layer in all sorghums are relatively small and like the endosperm are without color. The aleurone and endosperm color factors so prominent in corn have no apparent analogy in sorghum.

A knowledge of seed structure and its relation to the inheritance of seed color should aid in classifying and in determining the origin of the numerous sorghum hybrids that are constantly arising under field conditions.

SUMMARY

The inheritance of seed color in sorghums has been perplexing. A knowledge of seed-coat structure and the location of pigments in sorghum kernels as determined by microscopic observations gives a better basis for interpretation than has been available heretofore.

Pigmentation may occur (1) in the epidermal and hypodermal cells of the pericarp, (2) always in the nucellar layer when this structure is present, or (3) in both regions at the same time. The nucellar layer does not occur in all varieties.

B is assumed to be a factor the presence of which is responsible for the development of the nucellar layer and its associated pigment. Its recessive allelomorph, *b*, determines the absence of a nucellar layer and a consequent lack of any color due to nucellar pigmentation. There is some evidence that the *B* factor may cause a slight coloration in the epidermis of the pericarp when in combination with the factor *S*.

S is assumed to be a factor determining the development of a vestigial type of mesocarp, its recessive allelomorph, *s*, determining a well-developed, starchy, opaque mesocarp. A thick starchy mesocarp masks nucellar color and inhibits even a slight expression of color in the pericarp due to *B*.

R is a factor determining coloration in the epidermal and hypodermal cells of the pericarp, *r* being its allelomorph responsible for the absence of color in the pericarp. *R* is greatly intensified in the presence of *B* and *S*. Slight coloration in the pericarp due to the

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nucellar factor, B, is independent in its inheritance from the pericarp color factor, R, the interaction of these two factors producing a more intensive color in the presence of S.

The thickness of the mesocarp is a determining factor in the external expression of nucellar coloration. When about 70 μ in thickness the mesocarp masks nucellar color and completely inhibits any slight color that might occur in the pericarp due to the factor B. The mesocarp ranges in thickness from nothing in certain unclassified sorghum hybrids to 70 μ or more in feterita. Environmental influences may alter the development of the mesocarp and affect the expression of pericarp pigmentation to a certain degree, but for the most part it is believed that the thickness of the mesocarp in any variety of sorghum is a fairly constant heritable character.

The nucellar layer is a remnant of the nucellus that was not absorbed during the development of the embryo and endosperm. In some varieties of sorghum the nucellar layer is entirely absorbed. It was never more than one cell thick in any variety studied, and in seeds of Pink kafir only a thin remnant of the outside wall of the nucellar layer was found. A group of scattered nucellar cells overlaid by a thin mesocarp is believed to be responsible for the specks found in the seed coat of certain white-seeded kafirs.

There apparently are no endosperm or aleurone colors in sorghums such as occur in corn.

THE RELATION OF SODIUM NITRATE AND CERTAIN OTHER NITROGEN CARRIERS TO THE DEVELOPMENT OF CHLOROSIS IN RICE [1]

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INTRODUCTION

The relative value of nitrate and ammonium salts as sources of nitrogen for rice has been the subject of numerous investigations. In general it has been the conclusion from such investigations that ammonium salts are of decidedly greater value than nitrate salts for this purpose.

Various explanations have been offered for the failure of nitrates, under comparable conditions, to produce growth and yields of rice similar to those produced by ammonia. Unfavorable soil reaction, unavailability of iron, accumulation of poisonous nitrites when nitrates are reduced in submerged soils, and denitrification have been offered as explanations of the unfavorable results secured with nitrate nitrogen. Various investigators have attempted also to determine the cause of the development of chlorosis in rice. It was for the purpose of securing further experimental evidence concerning these questions that the work here reported was undertaken.

EXPERIMENTAL METHODS

A study was made of soil reaction and of nitrogen changes in both greenhouse and field soils. Three series of cultures were studied in the greenhouse. The soil used was taken from the experiment station farm and is classified as Clarksville silt loam. It had not been cropped to rice previously.

Corn was grown on it the previous year. The soil was taken from a slightly eroded spot and was therefore very low in organic matter and total nitrogen. It is of limestone origin, but croppir 2 and leaching have reduced its basic materials until it now show 12.1 8.9 9.8 acid reaction.

Gran 153 80 108

The soil was taken from the field, screened, thorou
and placed in glazed earthenware jars in the green
it remained from January 20 to March 14. No reduction of nitrates i
and no drainage was provided. Treatments were Nagaoka (9) found tha
and the experiments started. Common vetch reduction of nitrates to
bloom stage, cut into 1-inch segments and the writers in this and pre-
the soil, were used for green manure. Willis and Carrero (15) and
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that ammonia constitutes, in
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for the larger discrepancies,

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amount of ammonia might be available in these jars. Two jars of each treatment were cropped and two were not.

The rice plants were transplanted into the jars on March 16. All jars, cropped and uncropped, were flooded with distilled water 10 days later, March 26. Samples of soil were withdrawn from the jars at intervals during the experiment and analyzed for ammonia, nitrites, and nitrates. In certain of these analyses an exactly similar sample was extracted in the same manner and a 200 c. c. aliquot sample used for determination of total soluble nitrogen by the Kjeldahl method, modified to include nitrogen as nitrates. After distillation into standard acid the sample was Nesslerized in order that it might be strictly comparable to the ammonia determinations.

The first samples were taken from the dry soil just before the rice was transplanted, the second 25 days after the jars were flooded, the third 17 days later, and the fourth 15 days later. The results of these analyses are shown in Table 1. As in the previous work of the writers (*6*), nitrites were not present in significant quantities at any time, never exceeding 0.10 part per million parts of oven-dry soil. These results are, therefore, omitted from the table.

TABLE 1.—*Nitrogen as ammonia, nitrates, and total soluble nitrogen in variously treated soils sampled before and at intervals after flooding, together with the yield of rice straw in the cropped soil*

Jar No.	Treatment	First sampling, Mar. 16 (dry soil)		Second sampling, Apr. 20 (25 days after flooding)		Third sampling, May 7 (42 days after flooding)		Total soluble nitrogen	Fourth sampling, May 22 (57 days after flooding); parts per million of nitrogen present as—		Total soluble nitrogen	Yield of rice straw (dry weight)
		Parts per million of nitrogen present as—										
		NH_3	NO_3	NH_3	NO_3	NH_3	NO_3		NH_3	NO_3		
												Grams
258–259	Green manure, cropped	4.4	13.9	6.7	(1)	6.2	(1)	8.8	5.2	(1)	10.4	153.3
260–261	Green manure, no crop	4.7	13.3	13.9	(1)	56.2	(1)	49.8	38.9	(1)	38.4	-------
262–263	$NaNO_3$, cropped	2.9	26.8	4.1	(1)	6.0	(1)	5.5	7.7	(1)	7.2	80.5
264–265	$NaNO_3$, no crop	2.9	27.2	8.1	(1)	10.2	(1)	14.4	8.6	(1)	12.1	-------
266–267	$(NH_4)_2SO_4$, cropped	10.6	11.8	4.2	(1)	6.1	(1)	15.2	4.7	(1)	8.9	108.0
268–269	$(NH_4)_2SO_4$, no crop	10.5	11.6	8.6	(1)	16.4	(1)	21.6	9.9	(1)	9.8	-------

[1] Trace.

The results here shown indicate that the reduction of nitrates is very rapid in flooded soils. Kelley (*8*) and Nagaoka (*9*) found that sufficient nitrites were produced from the reduction of nitrates to exert a toxic effect on rice. The results of the writers in this and previous work (*6*) substantiate those of Willis and Carrero (*15*) and indicate that nitrites are probably not significant at any time in the soils investigated.

When the amounts of ammonia are compared with the figures for total soluble nitrogen it appears that ammonia constitutes, in most cases, nearly all of the total soluble nitrogen. The methods used may have been partially responsible for the larger discrepancies, the reasons for which are not clear.

It seems probable that some of the differences, in certain cases at least, between the amount of ammonia and the amount of total soluble nitrogen may have been due to amino nitrogen. Panganiban (*11*) found quantities of amino nitrogen in flooded rice soils ranging from 8.82 to 10.72 p. p. m. Using 2 per cent sodium hydroxide solution for extraction as recommended by Potter and Synder (*13*) and as used by Panganiban, and with a Van Slyke apparatus for making the determinations, the writers found as much as 10.7 p. p. m. of amino nitrogen in the jars to which sodium nitrate had been added. How much of this nitrogen is soluble in water and available to the plants is a question that has not been investigated.

Chlorosis became manifest in the plants treated with sodium nitrate by the close of the fifth week. It became pronounced by the close of the sixth week and persisted for nearly five weeks, when the plants began to assume a normal color again. Chlorosis also appeared in the plants treated with ammonium sulphate but came later, persisted for a shorter time, and was never so pronounced. The plants treated with green manure never showed a chlorotic condition.

Rice straw yields from this series are shown in Table 1. Since soil which has not been cropped to rice previously very frequently produces a great deal of sterility, otherwise designated as "straight head," one jar of each set of duplicates was allowed to become dry for a period of a week just previous to heading. Straight head, however, was only partially controlled, and grain yields, therefore, were not secured. The straw yields are averages of duplicates, as straw yields were not appreciably affected by drying the soil. Each jar contained 10 plants.

TOTAL-NITROGEN STUDIES

So far as the writers are aware no experimental results have been presented to show definitely what becomes of the nitrogen in a nitrate salt when the nitrate is reduced in a rice soil, though Kelley (*8*) and Nagaoka (*9*) presented evidence indicating that some of the nitrogen may be lost. It has been assumed in many cases that it is lost as free nitrogen, while in others it is assumed to be only partially reduced, nitrites, ammonia, or lesser oxidized forms of nitrogen resulting.

In the experiment just reported an attempt was made to solve this problem by studying the changes in total nitrogen. It was soon discovered, however, that the nitrogen as nitrate constituted too small a portion of the total nitrogen to enable the writers to detect changes. Accordingly, on May 1, a 200 gm. sample of finely pulverized, oven-dry soil containing 2 p. p. m. of nitrogen as nitrate was placed in each of three shaker bottles of 475 c. c. capacity. To each of these samples was added sufficient pure nitrate of soda to supply 0.1003 gm. of nitrogen. After the addition of 120 c. c. of distilled water the bottles were shaken in a mechanical shaker for one hour and then a sample was quickly removed from each with a wide-tipped pipette for analysis. A similar sample was removed for determination of the amount of dry soil in the sample. Each bottle was vigorously shaken by hand before the removal of a sample.

After the samples were removed the level of the water was carefully marked on the bottles and they were placed in a laboratory

where no chemicals were used in order that they might be kept from any ammonia in the air. A sample 1 c. c. in size was removed from each bottle at intervals in order to determine when all the nitrates were reduced, and each time the new level of the water was marked on the bottle. On July 12, samples were again analyzed for total nitrogen. Not all the nitrates had been reduced, but a qualitative test showed far less nitrates than the samples originally contained. It seemed best not to let them stand longer as algae had begun to appear. The water in the bottles was carefully made up to the mark and sampling was done as before. In order to check the accuracy of the total-nitrogen determinations the nitrates were determined by the phenoldisulphonic acid method and subtracted from that originally put in the soil. The results are recorded in Tables 2 and 3.

TABLE 2.—*Change in the total nitrogen content of soil, treated with sodium nitrate, after standing submerged*

Sample No	Total nitrogen on May 1	Total nitrogen on July 12
	Per cent	*Per cent*
1	0.087	0.053
2	.080	.055
3	.084	.052
Average	.0836	.0533

Average loss=0.0303 per cent or 303 p. p. m.

TABLE 3.—*Nitrate content of soil, treated with sodium nitrate, after standing submerged*

Sample No.	Parts per million of nitrogen as NO_3
1	132.8
2	246.6
3	161.6
Average	[a] 180.3

[a] This figure deducted from the N originally in the soil as NO_3, 501.5 p.p.m., gives an average loss of 321.3 p. p. m.

The results secured indicate the nitrogen is lost when nitrates are reduced, the loss in total nitrogen agreeing fairly well with the loss shown by the nitrate determinations. Hence, when a nitrate salt has been applied to a rice soil and has been reduced it is probable that the plant will suffer from a lack of available nitrogen.

INFLUENCE OF NITRATE NITROGEN ON DEVELOPMENT OF CHLOROSIS AND PLANT YIELD

The results of fertilizer trials in the United States and other countries have indicated, in general, that a nitrogen fertilizer whose nitrogen is present as nitrate is inferior for rice fertilization to one in which nitrogen is present as ammonia. Palisoc (*10*) reported good results with ammonium nitrate in solution cultures, but under such conditions nitrates are not reduced as in submerged soil. Trelease and

Paulino (*14*) reported better results with ammonium nitrate than with any other form of nitrate in soil, but obtained still further improvement with a nitrogen equivalent application of ammonium sulphate. Willis and Carrero (*15*) suggested that the nitrate radical was probably somewhat toxic or in some way contributed to a chlorotic condition of the plant. They suggested further a possibility that the sodium ion in itself is toxic to rice. This latter explanation was suggested to the writers by some work with solution cultures. In order, therefore, to determine whether or not these factors are operative a third series of experiments was planned.

It was assumed that, if the nitrate radical or the sodium ion contributed to the chlorotic condition of the plants, an increased concentration of either should increase chlorosis. It was further assumed that if the sodium ion was toxic to the rice plant then sodium chloride should produce a toxic effect. The series was accordingly arranged in five groups, as follows: Group 1 (jars 300–303) had an application of ammonium sulphate, on the basis of 50 pounds per acre, applied to each jar. Jar 300 had no further treatment. Jar 301 received sodium nitrate in addition to the ammonium sulphate at the rate of 50 pounds per acre. Jar 302 was similarly treated except that the sodium nitrate was applied at the rate of 150 pounds per acre. Jar 303 had sodium nitrate applied at the rate of 450 pounds per acre in addition to the ammonium sulphate.

Group 2 (jars 304–307) was treated like Group 1 except that calcium nitrate in equivalent quantities replaced the sodium nitrate. Group 3 (308–311) was also similar, but with ammonium nitrate in quantities sufficient to furnish an equivalent amount of nitrate nitrogen. Group 4 (312, 313) received ammonium sulphate at the rate of 50 pounds per acre, but jar 312 had sodium chloride added at the rate of 250 pounds per acre and jar 313 had calcium chloride added in sufficient quantity to give an equivalent amount of chlorine. The fifth group received only sodium nitrate, jar 314 having an application equivalent to 250 pounds per acre and jar 315 an application equivalent to 500 pounds per acre.

Chlorosis appeared in all the plants in the series except the two receiving the heavier applications of ammonium nitrate. The chlorosis appeared about a month after the plants were transplanted into the jars and persisted for a period of about four weeks. Even the plants in the jars receiving the heavier ammonium nitrate application showed some chlorosis near the close of this period, though it was never pronounced. After the four weeks' period all plants again attained a green color and grew vigoroulsy.

The plants receiving the heavier applications of sodium nitrate showed no more chlorosis than those receiving the lighter treatment. Those receiving sodium chloride had the same appearance as those receiving only ammonium sulphate. In so far as chlorosis is concerned the sodium ion did not appear to be responsible, as similar conditions obtained where calcium nitrate was used and also where the smaller amounts of ammonium sulphate were applied. Neither would it appear, therefore, that the nitrate radical produced the chlorotic condition.

Willis and Carrero (*15*) and Kelley (*8*) observed chlorosis in rice plants in early stages of growth, but it disappeared as the plants became older. Willis and Carrero reported chlorosis in proportion

to the quantity of nitrate added. The writers' results do not substantiate these findings. In the ammonium nitrate group the heavier the applications the less chlorosis appeared.

The plants in this series were not allowed to go to maturity, but were harvested at the age of 106 days and the weights of dry straw recorded. The results are shown in Table 4. The terms "light" "medium," and "heavy" are used to designate the relative rate of nitrate application. Each jar contained six plants.

TABLE 4.—*Yields of rice straw on soil receiving different quantities of nitrate and ammonium salts*

Group No.	Jar No.	Treatment	Yield of rice straw (dry weight)
			Grams
1	300	$(NH_4)_2SO_4$	12.8
	301	$(NH_4)_2SO_4$ + $NaNO_3$ (light)	12.8
	302	$(NH_4)_2SO_4$ + $NaNO_3$ (medium)	13.5
	303	$(NH_4)_2SO_4$ + $NaNO_3$ (heavy)	17.8
2	304	$(NH_4)_2SO_4$	13.0
	305	$(NH_4)_2SO_4$ + $Ca(NO_3)_2$ (light)	11.8
	306	$(NH_4)_2SO_4$ + $Ca(NO_3)_2$ (medium)	12.3
	307	$(NH_4)_2SO_4$ + $Ca(NO_3)_2$ (heavy)	18.8
3	308	$(NH_4)_2SO_4$	14.4
	309	$(NH_4)_2SO_4$ + NH_4NO_3 (light)	15.0
	310	$(NH_4)_2SO_4$ + NH_4NO_3 (medium)	20.2
	311	$(NH_4)_2SO_4$+NH_4NO_3 (heavy)	33.5
4	312	$(NH_4)_2SO_4$+$NaCl$	13.3
	313	$(NH_3)_2SO_4$+$CaCl_2$	13.5
5	314	$NaNO_3$ (medium)	10.8
	315	$NaNO_3$ (heavy)	15.0

EFFECT OF SUBMERGENCE ON HYDROGEN-ION CONCENTRATION OF SOIL AND PLANT YIELD

Willis and Carrero (*15*) at the Porto Rico station attempted to show the cause of the development of chlorosis in rice plants. Working with both calcareous and noncalcareous soil, they concluded that a lack of available iron was primarily responsible for the chlorosis. They thought it probable that the sodium ion in sodium nitrate, left as a residue in the soil when the nitrate was assimilated, was instrumental in inducing chlorosis. This, they said, was due to the change in reaction of the soil brought about by the basic residue.

The writers have observed chlorosis in rice plants in previous experiments. With these observations as a basis the second series of the present experiment was planned in such a way as to make it possible to study the relation of soil reaction and forms of nitrogen to chlorosis. It was designed to show whether soil reaction, involving the availability of iron, or the amount and availability of nitrogen was responsible for chlorosis. The soil, as stated previously, was not calcareous and its normal reaction was acid.

Very little work has ever been reported concerning the reaction of submerged soils. In those cases where such work has been reported (including previous work (*6*) by the writers) it was assumed that the reaction of the irrigation water was a reliable criterion of the reaction within the soil mass, and determinations of hydrogen-ion

concentration were made, therefore, on samples of the flood water. In the present experiment samples of soil were removed from the jars at frequent intervals for determination of the hydrogen-ion concentration. The soil in all jars was kept flooded continuously until about 10 days before the last samples were taken, when one of the duplicate jars of each treatment was allowed to become dry in order to determine what change would take place in the reaction. Distilled water with a reaction of pH 6.5 was used for irrigating the plants. The numbers of the jars and the corresponding treatments are shown in Table 5.

TABLE 5.—*Hydrogen-ion concentration of variously treated rice soils before and at intervals after flooding*

Jar No.	Treatment	Hydrogen-ion concentration of soils on—									
		Mar. 21 (original) [a]	Apr. 2	Apr. 9	Apr. 16	Apr. 23	Apr. 30	May 14	June 5	July 10	July 25
		pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
270	$NaNO_3$ flooded, cropped	5.7	5.5	5.7	5.9	5.9	5.9	5.9	6.0	6.4	6.4
271	Same as 270, but drained at finish	5.75	5.7	5.7	5.75	5.8	6.1	5.9	5.9	6.5	[b] 5.6
272	$NaNO_3$+iron sulphate spray to leaves, flooded, cropped	5.7	5.5	5.8	5.85	5.9	5.9	5.75	5.8	6.4	[b] 5.65
273	Same as 272 but drained at finish	5.7	5.5	5.8	5.8	5.8	6.0	5.8	5.8	6.2	6.5
274	$(NH_4)_2SO_4$, flooded, cropped	5.7	5.5	5.6	5.7	5.5	5.75	5.7	5.8	6.3	6.3
275	Same as 274, but drained at finish	5.7	5.6	5.6	5.6	5.5	5.7	5.7	5.7	6.1	[b] 5.7
276	No treatment, flooded, cropped	5.6	5.3	5.7	5.75	5.7	5.8	5.8	5.8	6.7	6.6
277	Same as 276, but drained at finish	5.75	5.5	5.9	6.1	5.8	5.8	5.7	5.9	6.5	[b] 6.0
278	No treatment, flooded, no crop	5.6	5.7	5.8	5.9	5.6	6.3	6.1	6.7	6.7	6.7
279	Same as 278, not drained	5.7	5.5	5.6	5.8	5.6	6.1	6.3	6.6	6.6	6.7
280	$NaNO_3$+sulphur, flooded, cropped	5.75	5.0	5.4	5.4	5.4	5.7	5.6	5.9	6.4	[b] 5.4
281	*Same as 280 but drained at finish*	*5.4*	*5.0*	*5.1*	*5.4*	*5.2*	*5.6*	*5.5*	*6.1*	*6.4*	*6.3*
282	$NaNO_3$ in 3 applications, sulphur, flooded, cropped	5.2	5.0	5.1	5.2	5.3	5.7	5.6	5.9	6.4	6.4
283	Same as 282 but drained at finish	5.5	5.0	5.1	5.3	5.3	5.6	5.75	6.2	6.4	[b] 5.2
284	$NaNO_3$+HCl to give reaction pH 4.0, flooded	4.0	5.1	5.1	5.2	5.2	5.7	5.5	6.3	6.0	6.1
285	Same as 284, not drained	4.0	5.1	5.2	5.4	5.5	5.6	5.7	6.2	5.9	6.1
286	$NaNO_3$ in 3 applications+HCl to give reaction pH 5.1, flooded cropped	5.1	5.4	5.5	5.4	5.5	5.6	5.6	5.7	6.5	6.3
287	Same as 286, but drained at finish	5.1	5.4	5.7	5.5	5.6	5.8	5.7	5.8	6.5	[b] 5.6
288	*No treatment, no crop, not flooded*	*5.6*	*5.5*	*5.5*	*5.6*	*5.6*	*5.8*	*5.6*	*5.8*	*5.9*	*5.7*
289	Same as 288	5.7	5.5	5.5	5.7	5.6	5.75	5.7	5.8	5.7	5.8
290	$NaNO_3$+HCl to give reaction of pH 5.1, flooded, cropped	5.1	5.2	5.2	5.3	5.2	5.4	5.4	5.8	5.9	6.3
291	Same as 290, not drained	5.1	5.6	5.3	5.3	5.2	5.5	5.2	5.5	5.7	5.7

[a] *The figures in this column represent the pH values of the soils just prior to submergence.*
[b] Allowed to become dry a week before determinations were made.

The sulphur in jars 280, 281, 282, and 283 was uninoculated and was applied to the soil at the rate of 900 pounds per acre two weeks before the plants were transplanted into the jars, and three weeks before the soil was submerged. Qualitative tests showed sulphates in these jars until 40 days after the plants were transplanted, at which time they seem to have been completely reduced.

Sodium nitrate was applied at the rate of 250 pounds per acre and, where not otherwise noted, in one application made before the plants were set into the jars. In jars 282, 283, 286, and 287 one-third was applied at this time, one-third when the plants were 47 days old, and one-third when they were 100 days old. Ammonium sulphate was applied at a rate sufficient to furnish nitrogen equivalent to that furnished by sodium nitrate.

In jars 284, 285, and 290, where hydrochloric acid was applied, the plants died. In jar 291 the plants lived to the close of the experiment, but made very poor growth. In jars 286 and 287 the plants grew well and matured, after being somewhat retarded by the acid treatment at the beginning of the experiment.

The results of the hydrogen-ion determinations are shown in Table 5. The first figure column represents the values for the dry soils just previous to submergence; the columns that follow show the values for flooded soil except where otherwise noted.

The data of Table 5 indicate that the flooding of the soil, in itself, changed the reaction decidedly toward alkalinity, the change being most rapid and attaining nearest the neutral point in jars 278 and 279 in which the soil was given no treatment, was flooded, and not cropped. The plants apparently tended to prevent this change as shown by a comparison of jars 276 and 277 with 278 and 279 and also jar 291, in which the plants lived, with jar 290, in which the plants died because of the application of hydrochloric acid. This tendency was probably due to the carbon dioxide excretions of the roots of the plants. Jacobson (*5*), starting with a culture solution having a reaction of pH 5.0 found that the rice plants changed the reaction to pH 3.0 during a period of three days. He believed root excretions of CO^2 were partially responsible for the change.

The change of reaction in the jars treated with ammonium sulphate was somewhat slower and did not attain quite the extent of that in the jars treated with sodium nitrate or in those that received no treatment. The difference was not marked, however. Even the sulphur and hydrocholoric acid treatments failed to prevent the change toward alkalinity.

When a number of the jars were allowed to become dry before the last samples were taken the reaction quickly reverted to near the original value. It would appear, therefore, that the change in reaction toward alkalinity was due to some incompletely oxidized compounds in the submerged soil.

The plants in all jars, except those treated with ammonium sulphate, began to show chlorosis as early as 35 days after the soil was submerged. At the end of 42 days the chlorosis was marked. At this time the reaction of the soil in the various jars ranged from pH 5.2 to pH 6.3, the least acid reaction of any cropped soil being pH 6.0, in one of the jars treated with sodium nitrate. After five weeks the plants began to show better color again and thereafter displayed no chlorotic symptoms. The plants in the jars treated with ammonium sulphate showed some chlorosis but it appeared later, lasted for a shorter period, and never became pronounced.

Sprayings of iron sulphate on the leaves of the plants in jars 272 and 273 failed to overcome chlorosis. An application of ferric citrate to the flood water in these jars likewise failed to improve the color of the plants. The second application of sodium nitrate, however, to jars 286, 287, 282, and 283 greatly improved the color of the plants and they never again showed marked chlorosis.

Rice yields from this series are shown in Table 6. The yields are the average of duplicates. Each jar in this series contained six plants.

TABLE 6.—*Rice straw yields from the soils used in studying soil hydrogen-ion concentrations*

Jar No.	Treatment	Yield of rice straw (dry weight)
		Grams
270-271	$NaNO_3$	62.5
272-273	$NaNO_3$+iron spray	55.9
274-275	$(NH_4)_2SO_4$	65.7
276-277	No treatment	51.8
280-281	$NaNO_3$+sulphur	61.8
282-283	$NaNO_3$ in 3 applications + sulphur	67.9
286-287	$NaNO_3$ in 3 applications + HCl	73.5
291	$NaNO_3$+HCl	15.5

FIELD STUDIES

In order to compare the changes in reaction and the nitrogen variations taking place under field conditions and in old rice soil with those observed in the greenhouse work, samples from certain of the fertility plots at the Rice Branch Experiment Station were analyzed. The soil of these plots is a typical rice soil of the Crowley series. The samples were taken in each case at such time as they could be shipped to the laboratory and analyzed the following day. While this arrangement was admittedly not so satisfactory as could be desired, owing to possible changes within the soil samples during transit, it apparently gave fairly reliable results. The samples were analyzed in the same manner as the greenhouse samples. The first samples were taken immediately after the ground was broken and before fertilizers were applied, the second after the fertilizers were applied and before irrigation began, the third four weeks after the soil was submerged, and the fourth eight weeks after submergence.

The rice station has been established rather recently and the plots employed in this work were used only one year previously for experimental work. The treatment given the various plots is shown in Table 7.

TABLE 7.—*Fertilizers added to experimental plots of rice soil at the Rice Branch Experiment Station*

Plot No.	Ammonium sulphate	Cottonseed meal	Superphosphate	Muriate of potash	Nitrate of soda	Hydrated lime
	Pounds per acre	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*
15	66	190	166	53		
16	132		331	53		
17 [a]						
18		380	273	40		
19			331	53	177	
20	58 (urea)		331	53		
21 [a]						
24						1,325
25 [a]						
26	132		331	53		1,325
28			331	53	177	1,325
29	58 (urea)		331	63		1,325

[a] This soil was given no treatment.

The nitrogen and soil reaction data for the samples from these plots are given in Table 8. Nitrite nitrogen was never present in significant amounts, the highest concentration being slightly less than 0.1 p. p. m. in plot 28. These values are, therefore, omitted from the table.

TABLE 8.—*Nitrogen as ammonia and nitrates and pH of variously fertilized soil from the rice station fertility plots*

Plot No.	First sampling (*before fertilization*)			Second sampling (*after fertilization*)			Third sampling (4 weeks after flooding)			Fourth sampling (8 weeks after flooding)		
	Parts per million of nitrogen present as—		pH	Parts per million of nitrogen present as—		pH	Parts per million of nitrogen present as—		pH	Parts per million of nitrogen present as—		pH
	NO_3	NH_3		NO_3	NH_3		NO_3	NH_3		NO_3	NH_3	
15	5.6	7.2	6.4	46.0	2.8	6.4	10.5	8.1	7.0	([1])	12.1	6.75
16	6.0	5.0	6.4	31.2	([1])	5.9	11.4	10.3	7.0	([1])	8.3	6.7
17	14.6	6.6	6.2	10.2	([1])	6.4	10.8	12.4	6.8	([1])	29.8	7.0
18	5.1	6.1	6.4	9.8	2.3	6.2	36.1	9.5	7.3	([1])	12.4	7.0
19	10.0	6.9	6.3	28.4	1.8	6.2	16.2	11.0	7.2	([1])	7.8	6.8
20	*12.9*	*4.4*	*6.7*	*11.4*	*2.0*	*6.0*	*11.7*	*10.5*	*6.9*	([1])	*27.6*	6.8
21	10.0	6.7	6.3	9.4	2.1	6.0	11.7	12.3	6.9	([1])	8.1	6.8
24	13.5	9.3	6.1	17.6	2.6	7.7	10.1	7.8	7.3	([1])	11.6	7.1
25	5.5	8.5	6.1	9.8	([1])	6.0	13.7	6.1	6.9	([1])	8.3	6.9
26	9.2	4.8	6.5	23.4	([1])	7.6	18.9	11.3	7.2	([1])	9.2	6.9
28	14.0	7.4	6.5	32.2	2.0	7.7	17.3	9.7	7.3	([1])	23.5	6.9
29	25.0	6.2	6.1	19.0	1.8	7.3	10.5	8.4	7.2	([1])	27.7	7.0

[1] Trace.

None of the plants showed chlorotic symptoms except those in the four limed plots. These showed some chlorosis, which persisted for a considerable period. In plots 18 and 19, where the reaction became slightly alkaline, the plants retained a healthly, green color.

The soil in these plots contained a rather large amount of organic matter, much more than did the soil used in the greenhouse work. This high organic content made possible a comparatively high rate of ammonification as shown by the amounts of ammonia present in the soil within one month after submergence. These values were appreciably higher than for the cropped jars in the greenhouse at the corresponding sampling.

The irrigation water used on the field plots had a reaction of pH 7.3. Qualitative tests of the water showed that it contained small amounts of chlorides and sulphates, about 3.5 p. p. m. of nitrates, a trace of nitrites and ammonia, a large amount of bicarbonates, and a rather high content of salts precipitated by ammonia.

DISCUSSION

The evidence presented in the foregoing experiments indicates that insufficient available nitrogen, particularly ammonia, was responsible for chlorosis in the plants. That the chlorotic condition was not due to changes in soil reaction rendering the iron of the soil unavailable, as suggested by Willis and Carrero (*15*), was indicated by the following facts: (1) The reaction was pH 6.0, and lower in certain jars, when chlorosis became marked and iron was very probably not rendered unavailable with this reaction; (2) iron sulphate spray applied to the leaves of the plants failed to overcome chlorosis, as was

true in the work of Willis and Carrero, though they thought its failure was due to failure of the spray to cover the leaves; (3) iron citrate added to the flood water had no remedial effect on the plants; (4) addition of the second application of sodium nitrate to certain jars during the period when the plants were most chlorotic greatly improved the appearance of the plants and they never again showed marked chlorosis; (5) where ammonium nitrate was added in heavy applications very little chlorosis appeared; (6) in those jars to which light applications of ammonium sulphate were made, chlorosis became pronounced; and finally (7) no chlorosis appeared where an application of 12 tons per acre of green manure had been made, due, very probably, to the steady evolution of rather large amounts of ammonia.

Gile and Carrero (*2*) observed chlorosis in rice on dry soil and found that it disappeared after the soil had been submerged. This disappearance they attributed to the development of roots under submerged conditions which were more capable of assimilating iron. Johnson (*7*), writing of this work, attributed the disappearance of chlorosis to the reduction of iron under submerged conditions from the ferric to the ferrous form, rendering it available to the plants. Willis and Carrero (*15*) further found that organic iron compounds were ineffective in preventing chlorosis. When bulky organic compounds such as stable manure, velvet-bean plants, and tobacco stems were used in considerable quantities, however, the condition was overcome, due, they thought, to the fact that the presence of these compounds enabled the plants to obtain more iron.

Much of the work of these investigators was done on calcareous soil and therein differed from the conditions under which the present writers worked. The results of the writers' experiments, however, would indicate that the reason the chlorosis observed by Gile and Carrero was overcome by submergence, was probably the evolution of ammonia after the soil was submerged. Ammonification undoubtedly took place in the dry soil, but the ammonia so produced was rapidly converted into nitrites and subsequently into nitrates. The writers have shown in a previous publication (*6*) that rice plants grow well in a dry soil if considerable ammonia is present, expecially in the early stages of growth. The bulky organic material added by Willis and Carrero probably greatly stimulated ammonification and thereby proved valuable also in overcoming the chlorotic condition. Arrhenius (*1*) has reported a "rather good rice soil" with a reaction of pH 7.0, with the significant statement that it was "very rich in humus." He expressed the belief that root excretions of carbon dioxide and other substances accumulate in the soil layer around the roots of rice plants where they act as amphoteric electrolytes changing the reaction in such manner as to enable the plant to maintain conditions favorable for growth.

The nitrogen of sodium nitrate or other nitrate salts is probably lost in the process of reduction, as indicated in this study, and the plant becomes chlorotic due to a lack of nitrogen before ammonification has progressed sufficiently to enable it to secure enough nitrogen. As ammonification proceeds the condition is overcome. Where large amounts of organic matter are present, as in the soil treated with green manure and the field soil used in this work, severe chlorotic conditions are probably not to be expected.

In the light of these investigations, sodium nitrate, or other nitrate salts can hardly be recommended for rice fertilization. If used, it would appear most economical to apply it in several applications in order to minimize the loss from denitrification.

SUMMARY

A study of the effect of sodium nitrate upon the reaction of rice soils, and upon nitrogen changes in such soils, has been reported in this paper. Soils treated with green manure and ammonium sulphate were also studied for purposes of comparison. Both greenhouse and field soils were used in the work.

Sodium nitrate and other nitrates were rapidly reduced in submerged soil. The experimental results indicate that nitrogen was lost in the reduction process by denitrification. Ammonification progressed slowly for the first four or five weeks following submergence except where an abundance of organic matter was present. Consequently, the plants suffered from lack of available nitrogen and became chlorotic. Chlorosis was overcome as ammonification progressed.

The soil reaction was changed toward alkalinity by flooding. Sodium nitrate had a slight tendency to hasten this change and ammonium sulphate tended slightly to retard it. Chlorosis became marked in nearly all cases before the soil reaction reached pH 6.0. An impaired availability of iron due to an alkaline reaction of the soil very probably was not, therefore, the cause of chlorosis.

Where an abundance of organic matter was present in greenhouse soil and in field soil chlorosis did not appear. This was due, very probably, to ammonia liberated from the organic matter. The reaction of the field soil reached pH 7.0 and slightly above in some cases. Where lime was applied to field soil some chlorosis appeared.

Spraying ferrous sulphate on the leaves of chlorotic plants failed to correct the condition. The addition of ferric citrate to the flood water for this purpose likewise failed.

A second application of nitrogen, while the plants were chlorotic, greatly improved their color and vigor. This appears to be good evidence that chlorosis was due to lack of available nitrogen, particularly lack of ammonia in early stages of growth.

LITERATURE CITED

(1) ARRHENIUS, O.
1922. A POSSIBLE CORRELATION BETWEEN THE FERTILITY OF RICE SOILS AND THEIR TITRATION CURVES. Soil Sci. 14: 21–26, illus.

(2) GILE, P. L., and CARRERO, J. O.
1920. CAUSE OF LIME-INDUCED CHLOROSIS AND AVAILABILITY OF IRON IN THE SOIL. Jour. Agr. Research 20: 33–62, illus.

(3) GILLESPIE, L. J.
1920. COLORIMETRIC DETERMINATION OF HYDROGEN-ION CONCENTRATION WITHOUT BUFFER MIXTURES, WITH ESPECIAL REFERENCE TO SOILS. Soil Sci. 9: 115–136, illus.

(4) HARPER, H. J.
1924. THE ACCURATE DETERMINATION OF NITRATES IN SOILS. PHENOLDISULPHONIC ACID METHOD. Indus. and Engin. Chem. 16: 180–183.

(5) JACOBSON, H. G. M.
1925. CHANGES IN HYDROGEN-ION CONCENTRATION IN NUTRIENT SOLUTIONS. II. IN CULTURES WITH RICE. Jour. Amer. Soc. Agron. 17: 583–586.

(6) JANSSEN, G., and METZGER, W. H.
1928. TRANSFORMATION OF NITROGEN IN RICE SOIL. Jour. Amer. Soc. Agron. 20: 459–476, illus.

(7) JOHNSON, M. O.
1924. MANGANESE CHLOROSIS OF PINEAPPLES: ITS CAUSE AND CONTROL. Hawaii Agr. Expt. Sta. Bul. 52, 38 p., illus.

(8) KELLEY, W. P.
1911. THE ASSIMILATION OF NITROGEN BY RICE. Hawaii Agr. Expt. Sta. Bul. 24, 20 p.

(9) NAGAOKA, M.
1904. ON THE BEHAVIOR OF THE RICE PLANT TO NITRATES AND AMMONIUM SALTS. Bul. Col. Agr., Tokyo Imp. Univ. 6: [285]–334, illus.

(10) PALISOC, E.
1928. COMPARATIVE NUTRITIVE VALUES OF DIFFERENT SALTS OF AMMONIUM. Philippine Agr. 17: 37–43.

(11) PANGANIBAN, E. H.
1923. RATE OF DECOMPOSITION OF ORGANIC NITROGEN IN RICE PADDY SOILS. Philippine Agr. 12: 63–75.

(12) PIERRE, W. H., and PARKER, F. W.
1927. THE USE OF COLLODION SACKS IN OBTAINING CLEAR SOIL EXTRACTS FOR THE DETERMINATION OF THE WATER-SOLUBLE CONSTITUENTS. Soil Sci. 23: 13–32.

(13) POTTER, R. S., and SNYDER, R. S.
1915. DETERMINATION OF AMINO ACIDS AND NITRATES IN SOILS. Iowa Agr. Expt. Sta. Research Bul. 24, p. [327]–352, illus.

(14) TRELEASE, S. F., and PAULINO, P.
1920. THE EFFECT ON THE GROWTH OF RICE OF THE ADDITION OF AMMONIUM AND NITRATE SALTS TO SOIL CULTURES. Philippine Agr. 8: [293]–313, illus.

(15) WILLIS, L. G., and CARRERO, J. O.
1923. INFLUENCE OF SOME NITROGENOUS FERTILIZERS ON THE DEVELOPMENT OF CHLOROSIS IN RICE. Jour. Agr. Research 24: 621–640.

STUDIES OF THE PHOTOPERIODISM OF SOME ECONOMIC PLANTS[1]

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INTRODUCTION

In the spring of 1924 a study of the effect of certain seasonal day lengths on some economic plants was undertaken at the Porto Rico Agricultural Experiment Station at Mayaguez. At this latitude, 18° 12′ N., the time between sunrise and sunset ranges from 11 hours in December to 13.2 hours in June. In neither December nor June is the variation in day length within the month greater than six minutes.

METHODS OF EXPERIMENTATION

For the purpose of the test the plants were grown in three groups, under respectively a long, a short, and the normal daily light exposure. For the long exposure, electric lights were automatically switched on at sunset and off at 13½ hours after sunrise, thus furnishing a lighted period approximating in length that of June days at this latitude. Five 50-watt mazda blue "daylight" bulbs were set 2½ feet apart in a row above the containers in which the plants were grown, the distance from the bulbs to the soil surface being not more, and usually considerably less, than 5 feet. At the soil surface the intensity of illumination was 5½ to 6 candlepower, and half way to the lamps it was 15 candlepower.

The plants receiving the short daily light exposure were placed on cars which were run into a dark room in the latter part of the night and brought out into the light at 11 hours before sunset. This light exposure in length approximately corresponded to December days at this latitude, differing, however, in having but the single daily twilight.

Sweet potatoes, onions, pineapples, and beans were grown under the daily light exposures outlined above. In addition, the onions, pineapples, and potatoes were grown under daily light exposures, differing from the normal in slightly more exaggerated degree, of 10 and 15 hours' duration, respectively, and corn was grown under a 15-hour exposure. Though the duration of exposure to light is referred to in terms of hours with the sun above the horizon or the lighted period artificially protracted, each period also included in addition the single brief tropical twilight exposure.

For corn and for some of the plants which were grown in containers as well, a garden plot was electrically illuminated from sunset to 15 hours after sunrise. Five rows of lights were placed 5 feet apart. Each row contained four 40-watt lamps spaced 6½ feet apart. The lights were set 3 feet above the soil surface at planting and so remained over the low-growing plants, but were gradually raised over the

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tall-growing plants, such as corn, as growth made it necessary. At the surface of the ground the intensity of illumination ranged from 3.4 or 3.5 to 5 candlepower over the beds of low-growing plants. The intensity of illumination at the base of the tall corn was reduced to 1 or less candlepower after the ultimate lifting of the lights.

The check plants were grown in a plot that was sufficiently removed from the treated plot to be unaffected by the light from it.

PLANTS STUDIED

SWEET POTATOES

Two varieties of sweet potatoes, Porto Rico and Key West, were grown. Fourteen plantings were made between March 11, 1924, and June 30, 1925, at intervals of 4 to 8 weeks. The containers used were 5-gallon tin cans, each carrying river loam in amount equivalent to 50 pounds of moisture-free soil. At each planting the draws or slips for the different groups were derived from a single tuber. The vines were trained on wire screening so placed as to utilize the illumination to the best advantage. The first 2 plantings were run for 16 and 20 weeks, respectively, and subsequent plantings for 24 weeks. In addition to the plants which passed the entire period without change of light exposure, in 3 plantings other plants, after having passed half the period under either the long or the short daily light exposure, were transferred to the other exposure. Blossoming and production of vine growth and tubers were noted.

The shorter daily light exposure proved to be more favorable to the blossoming of both varieties. Four plants of the Porto Rico variety blossomed, and a fifth budded under the shorter exposure, two blossomed under the normal, and none whatever under the longer exposure. Of the Key West variety, 8 blossomed under the shorter, 6 under the normal, and 3 under the longer daily light exposure.

The evidence as to the effect of length of daily light exposure on vine growth and tuber formation was inconclusive. The curves of both growth and production under the different light exposures follow the same general trend.

Special conditions modified the growth of one planting of Porto Rico and five plantings of Key West, thus necessitating their elimination from comparisons of vine growth and tuber production. There remained for purposes of comparison 22 individuals under each light exposure. The behavior of the two varieties did not differ essentially and their data are combined in Table 1.

TABLE 1.—*Vine growth and tuber production of sweet potatoes under 11-hour, normal, and 13½-hour daily light exposures*

Length of daily light exposure	Data from 13 individuals under each light exposure			Data from 22 individuals under each light exposure					
	Length of vine growth alive on removal	Length of vine growth dead on removal	Total length of vine growth on removal	Weight of vine growth	Weight of tubers	Weight of tubers plus other roots recovered	Number of tubers weighing 100 or more grams	Number of tubers weighing 50 to 99 grams	Number of tubers weighing 1 to 49 grams
	Inches	*Inches*	*Inches*	*Grams*	*Grams*	*Grams*			
11 hours	1,885	918	2,803	2,131	4,839	5,257	18	16	57
Normal	1,887	743	2,630	3,450	4,855	5,516	18	13	41

The uniformity under the different light exposures was notable in respect to length of vine growth, total weight of tubers, and grading of tubers as to size. Too much importance should not be attached to the fact that the weight of vine growth was considerably less under the short light exposure, since the weight of vine growth was greater under the normal exposure than under the long exposure in 13 of 22 comparisons.

ONIONS

Four varieties of onions, Prizetaker, Bermuda White, Yellow Globe Danvers, and Silver King (Giant White Tripoli), were grown under the different light exposures. Plantings were made at four-week intervals from August 22 to December 12, 1925, and again on January 7, 1927. Because of poor seed, Yellow Globe Danvers and Silver King (Giant White Tripoli) were eliminated from the first planting, and the latter from the second planting as well. The soil and containers were like those used for sweet potatoes. Suitable fertilizer

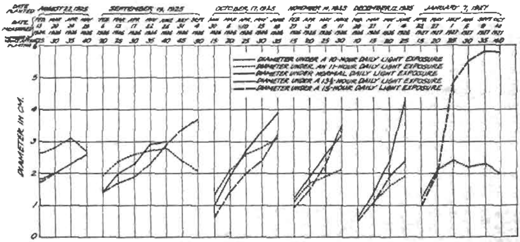

FIG. 1.—Average diameter of Prizetaker onions grown under daily light exposures of different lengths

was uniformly mixed with the soil prior to planting. The seedlings of the first planting were germinated under a normal light exposure and transplanted to the containers in the different groups at two weeks after seeding. In subsequent plantings the seed was planted in the permanent container and the resultant seedlings were kept under the different light exposures from the start. Five were left to develop in each container.

Four or more measurements of the diameter of the bulb or pseudostem of each plant were taken at intervals of five weeks. The increase in diameter of the different varieties under the different light exposures is shown graphically in Figures 1, 2, 3, and 4.

The onions of two plantings were allowed to continue growth for considerably more than a year, whereas those of the other plantings were removed, weighed, and measured at 25, 30, 35, and 40 weeks after planting.[2]

[2] Two varieties were removed on three occasions on the day prior to the termination of the week in order to facilitate note taking. This difference is disregarded.

PRIZETAKER

The Prizetaker under an 11-hour daily light exposure formed no bulbs,[3] the plants remaining in the spring-onion stage, with comparatively

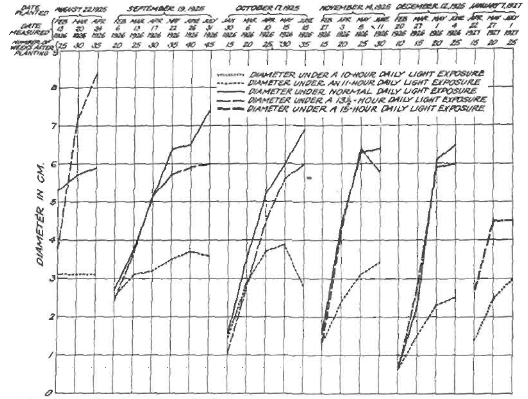

FIG. 2.—Average diameter of Bermuda White onions grown under daily light exposures of different lengths

slender pseudostems, and green leaves. In the planting allowed to continue growth for the longest period, about 15 months, the stalk or pseudostem of these ancient spring onions measured 17 to 20 cm. from root base to the point of leaf spread, and only 1.2 to 1.4 cm. in diameter.

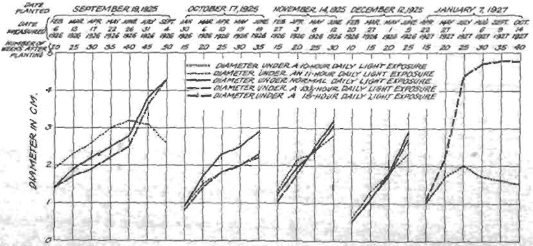

FIG. 3.—Average diameter of Yellow Globe Danvers onions grown under daily light exposures of different lengths

Under the normal light exposure there was some basal swelling of the pseudostems, but most individuals were still in the spring-onion

[3] The term "bulb" in this discussion is not used in its botanical sense, but to designate the normal globular

stage.[9] In the lot planted November 14 and removed June 11, one of the five plants had developed a well-formed bulb 5.8 cm. in diameter, and the tops, though still green, had fallen over on removal at 30 weeks, whereas the others in the container were in the spring-onion stage with erect turgid tops. In the lot planted December 12 and removed June 4, bulbs of considerable size had formed. Since with one exception the tops were still growing and were larger and more turgid than under the shorter light exposure, the stage of development appeared to be intermediate between that of spring onions and matured bulbs.

Under the 13½-hour daily light exposure, as in the other groups, the development was mainly that of spring onions, although some were slightly swollen near the base. Of those planted December 12, one had developed a bulb comparable to those in the normal-day group, though smaller. At the time of removal there was little difference in duration of daily light exposure between the normal and the 13½-hour exposure. The relative proportions of tops to pseudostems or bulbs are given in Table 2 and show that the plants went chiefly to tops under daily light exposures of 11 to 13½ hours. (Fig. 5, A.)

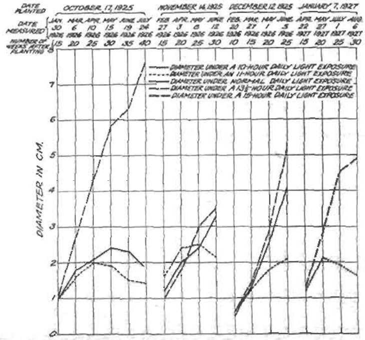

FIG. 4.—Average diameter of Silver King (Giant White Tripoli) onions grown under daily light exposures of different lengths

The plantings of January, 1927, were given different exposures from the preceding. Under a 10-hour daily light exposure all were still in a vigorously growing spring-onion condition at 60 weeks. In two instances, however, the basal portion of the pseudostem was slightly swollen. On the other hand, under a 15-hour daily light exposure, four bulbs had formed at 25 weeks and the tops of two had fallen over, an indication that they were approaching the rest period. Their condition in the twenty-ninth week is shown in Figure 5, B. At 30 weeks all had formed bulbs, and at 35 weeks the tops of three were dead and those of the others were dying. At 40 weeks the first of these had gone through the resting period and resumed growth.

There was no evidence as to any effect of length of daily light exposure on division or splitting of the individual into more than one. No individual of the planting of October 17 showed any splitting, whereas individuals in the following planting showed some splitting under the 11-hour, the normal, and the 13½-hour daily light exposures. On the whole, the splitting averaged the same for the three groups, one splitting into 1.2. In the single planting under a 10-hour exposure no splitting occurred; under the 15-hour exposure one of the five individuals had split into two prior to entering the rest period.

TABLE 2.—*Relation of tops*[a] *to bulbs or pseudostems of four onion varieties which were grown under 11-hour, normal, and 13½-hour daily light exposures*

Variety and portions weighed	Length of daily exposure	Average weight per plant of onions— Planted Aug 22, 1925, and removed 40 weeks later	Planted Oct. 17, 1925, and removed 35 weeks later[b]	Planted Nov. 14, 1925, and removed 30 weeks later	Planted Dec. 12, 1925, and removed 25 weeks later	Total weight	Total weight expressed in percentage of weight of tops
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Prizetaker:							
Tops	11 hours	78	61	54	29	222	100
Pseudostems	11 hours	51	42	33	19	145	65
Tops	Normal	68	66	60	53	247	100
Pseudostems or bulbs	Normal	31	60	59	55	205	83
Tops	13½ hours	75	66	75	57	273	100
Pseudostems or bulbs	13½ hours	36	43	46	27	152	56
Bermuda White:							
Tops	11 hours	59	30	17	31	137	100
Pseudostems or bulbs	11 hours	48	57	60	37	202	147
Tops	Normal	20	4	1	1	26	100
Bulbs	Normal	185	125	103	97	510	1, 961
Tops	13½ hours	1	7	0	0	8	100
Bulbs	13½ hours	229	89	84	81	483	6, 038
Yellow Globe Danvers:							
Tops	11 hours	--------	57	67	53	177	100
Pseudostems	11 hours	--------	29	35	28	92	52
Tops	Normal	--------	57	74	69	200	100
Pseudostems	Normal	--------	33	49	33	115	58
Tops	13½ hours	--------	66	81	61	208	100
Pseudostems	13½ hours	--------	29	43	26	98	47
Silver King (Giant White Tripoli):							
Tops	11 hours	--------	49	85	61	195	100
Pseudostems	11 hours	--------	24	50	27	101	52
Tops	Normal	--------	--------	78	77	155	100
Pseudostems or bulbs	Normal	--------	--------	62	47	109	70
Tops	13½ hours	--------	28	57	65	150	100
Pseudostems or bulbs	13½ hours	--------	63	64	87	214	143

[a] Where a bulb had failed to develop, the division between top and pseudostem was made by cutting just below the spread of leaves.

[b] This applies to all except Silver King (Giant White Tripoli), which in this planting was left for nearly 61 weeks.

BERMUDA WHITE

Under the 10-hour daily light exposure the plants of the Bermuda White variety remained in the spring-onion condition. At 60 weeks there were 15 plants instead of the 5 original plants, but development had been made without prior bulb formation or a rest period. A slightly swollen base was the nearest approach to bulb formation.

Similarly, under an 11-hour daily light exposure the development for the most part was that of spring onions. Of those in the five plantings only one individual developed bulbs. On removal at 30 weeks after planting this had developed two poor bulbs, one of which contained two individuals.

In contrast to those under a shorter than normal light exposure, all plants grown under the normal light exposure developed normal bulbs. At 25 to 30 weeks these generally were entering or had entered the rest period. The first resumption of growth in two containers was at 35 and 39 weeks, respectively.

Under a 13½-hour daily light exposure, well-formed bulbs developed. On some of these the tops had fallen over at 20 weeks, and were dead at 22 weeks. In one instance growth was resumed at 27 weeks.

The plants under the 13½-hour and under the normal exposure, which in June closely approached the former in duration, showed in general a pronounced similarity in rate of increase in diameter.

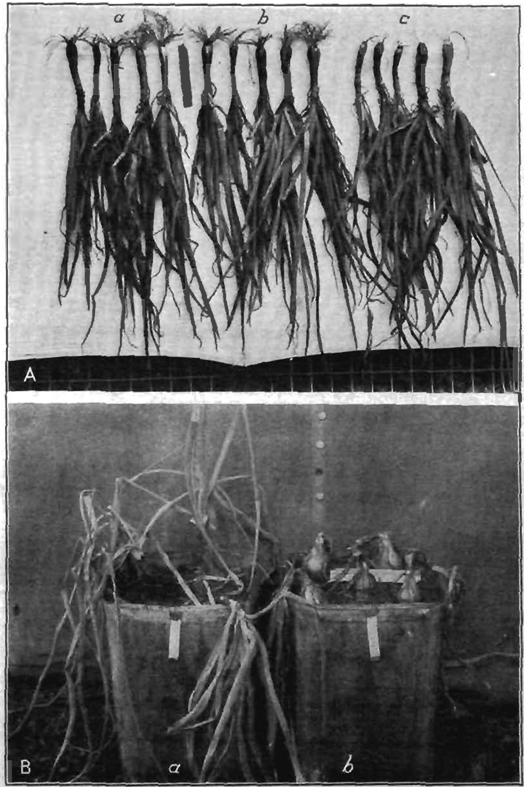

FIG. 5.—Prizetaker onions. A, Light exposures of *a*, 11 hours; *b*, normal; and *c*, 13½ hours. October 17 to June 18. B, Light exposures of *a*, 10, and *b*, 15 hours. January 7 to July 27

(See fig. 2.) The contrasts in proportional development under th[e] different light exposures were striking. (See Table 2.) Figure 6. A

Under the 15-hour daily light exposure bulbs developed rapidly, though they were somewhat smaller. At 15 weeks four bulbs had developed and the fifth was intermediate in form. At 18 weeks the

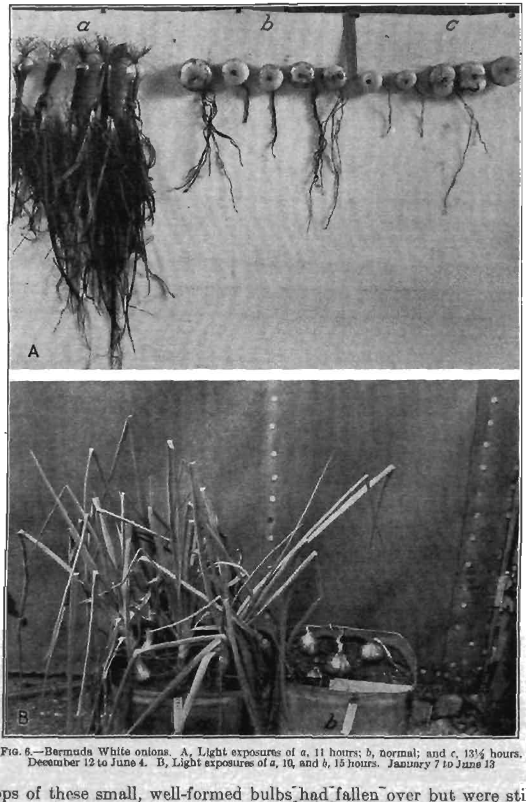

FIG. 6.—Bermuda White onions. A, Light exposures of *a*, 11 hours; *b*, normal; and *c*, 13½ hours. December 12 to June 4. B, Light exposures of *a*, 10, and *b*, 15 hours. January 7 to June 13

tops of these small, well-formed bulbs had fallen over but were still green. At 20 weeks the tops were dead or dying. At this time the leaf development of this lot was in striking contrast to that of the plants grown under a 10-hour exposure. The longest leaf per plant

of the former averaged 20 inches in length, in contrast to an average length of 31.6 inches under the 10-hour exposure, measuring from soil surface to leaf apex. The condition of the plants in the twenty-third week is shown in Figure 6, B. At 25 weeks one plant had terminated the resting stage and resumed growth. After the remaining plants had resumed growth, all were removed but one, as they were infected with *Sclerotium rolfsii*. The remaining one resumed growth at 29 weeks. At 40 weeks five well-formed small bulbs had developed from it, and the tops had fallen over. At 42 weeks the plants had entered the resting stage and the tops were dead. At 45 weeks one plant had resumed growth, and at 50 weeks all were again growing. Thus, within the year two growth periods and two rest periods were terminated and a third period of growth was entered upon. At 60 weeks the plants had the appearance of vigorous young spring onions. No indication of blossoming appeared at any time.

Among the plants which had formed bulbs the development of more than 1 core was often shown on resumption of growth, 2 individuals arising from what had externally appeared to be a perfectly formed single-cored bulb. Of the plantings grown in 20 containers under the different daily light exposures, only 1 failed to show splitting of 1 or more individuals. Under the 11-hour exposure, splitting was in the proportion of 1 to 2.1, and under the 13½-hour exposure, of 1 to 2.2. At 35 weeks 13 individuals, 1 with 3 cores, had developed from the 5 plants under a 10-hour exposure, and 12 individuals, 1 with 2 cores, had developed from the 4 plants in the contemporary lot under a 15-hour exposure, the rest period of the latter having been terminated and growth resumed. Owing to vigorous top growth and the absence of bulb formation, the splitting of 1 individual into several was more conspicuous under the shorter exposures than under the longer daily light exposures, where bulbs were quickly formed and the rest period was entered. On resumption of growth, however, the compound formation under the longer exposures became evident.

Yellow Globe Danvers

Plants of the Yellow Globe Danvers variety under a 10-hour daily light exposure were still in the spring-onion stage at 60 weeks after planting.

Plants removed at 25 to 35 weeks after planting showed comparatively little difference in development under daily light exposures of 11 hours, normal length, and 13½ hours. (See Table 2.) All had green tops and long pseudostems. (Fig. 7, A.) The basal section of the pseudostem generally was more swollen under the normal exposure than under the 11-hour exposure. In the planting of December 12, 1 individual under the 13½-hour exposure progressed beyond the spring-onion stage and developed a swollen base. Otherwise, all were classed as spring onions.

The planting of September 19 was left for a longer period. At 45 weeks after planting, 1 or 2 plants in each container had rotted, and the others were still in the spring-onion stage, though under the 13½-hour exposure 1 of the 4 individuals showed a much swollen base. At 50 weeks the basal diameters averaged 2.6 cm. under the 11-hour exposure, and 4.3 cm. under the normal and the 13½-hour

exposures, showing the tendency of the 2 latter toward bulb formation. Rotting eliminated the normal-day group. The 3 individuals remaining under the 13½-hour exposure had formed

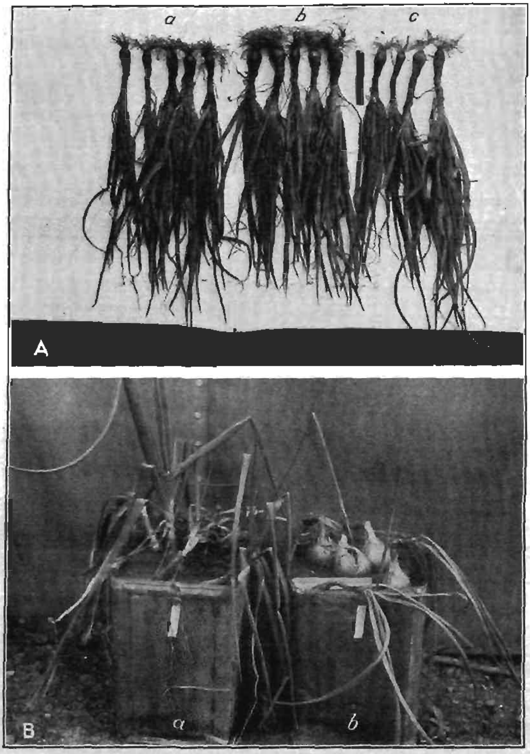

FIG. 7.—Yellow Globe Danvers onions. A, Light exposures of *a*, 11 hours; *b*, normal; and *c*, 13½ hours. October 17 to June 19. B, Light exposures of *a*, 10, and *b*, 15 hours. January 7 to July 26

small bulbs with tops over at 50 weeks, and tops dead at 51 weeks. Of these a single individual remained on removal at a little less than 65 weeks. It had gone through the resting stage and just resumed

growth. The bulb weighed 23 gm. and measured 3.7 cm. in horizontal by 4 cm. in vertical diameter.

Under a 15-hour exposure bulb formation was rapid. At 25 weeks all had formed or were forming bulbs and the top of 1 was already over. The pronounced degree of difference is very evident on comparing the average diameters at 25 weeks under the different daily light exposures. (See fig. 3.) At 27 weeks all had developed bulbs and the tops of 4 had fallen over. Their condition in the twenty-ninth week is shown in Figure 7, B. At 31 weeks all tops had died. In the thirty-ninth week 1 plant had terminated the rest period and resumed growth. Prior to the forty-fifth week two plants had rotted. Of the remaining 3, the outer leaf scales had sloughed off, leaving in place of the old bulbs "spring" onions with new leaf growth.

Of 81 plants of this variety, only 3 showed compound formation or splitting, 1 under the 11-hour, another under the normal, and the third under the 15-hour daily light exposure. Here again splitting was not shown to be correlated with the length of daily light exposure.

Silver King (Giant White Tripoli)

Plants of the Silver King (Giant White Tripoli) variety grown under a 10-hour daily light exposure were still in the spring-onion stage at 60 weeks after planting, never having formed bulbs. Similarly, plants grown under an 11-hour exposure for 25, 30, and nearly 61 weeks remained in the condition of spring onions.

Three lots were grown under a normal light exposure. Of those planted December 12 and removed June 5, 25 weeks after planting, one had formed a good bulb which had rotted prior to removal. Although the others showed more basal swelling of the pseudostems than those in the lot grown under an 11-hour daily light exposure, they had progressed little, if any, beyond the spring-onion stage of development. Those planted November 14 on removal June 12, 30 weeks after planting, were all in the spring-onion stage but showed some basal swelling. Of those planted October 17 all were in the spring-onion stage with tops green, upright, and turgid at 35 weeks after planting, June 19. Disease entered a little later and eliminated this lot.

Though development was not uniform under a 13½-hour daily light exposure, the effect of the longer exposure on bulb formation was very evident. In the lot of 5 planted December 12 and removed at 25 weeks, 2 were unmodified spring onions, and the other 3 had developed a total of 5 bulbs. One bulb was well formed, 2 bulbs were moderately well formed, and 2 were a little more than half-formed, all with tops over. (Fig. 8, A.) Their diameter ranged from 5 to 7.6 cm. Of the lot planted November 14 and removed at 30 weeks after planting, 3 were spring onions 2 of which were compound, and a fourth had a much swollen base, whereas the remaining plant had developed a well-formed bulb with top over. Only 2 plants of those planted October 17 survived. As early as 25 weeks after planting 1 showed itself to be compounded of 2 individuals. At 40 weeks 3 bulbs had formed, measuring 6.1, 6.8, and 9.8 cm. in diameter. The top of 1 was over and that of another was dead. The first appearance

of new growth was in the forty-first week. On removal at more than 60 weeks after planting, there were 3 plants in vigorous leaf growth, 1 bulb, and 2 spring onions, which had arisen from the old bulbs.

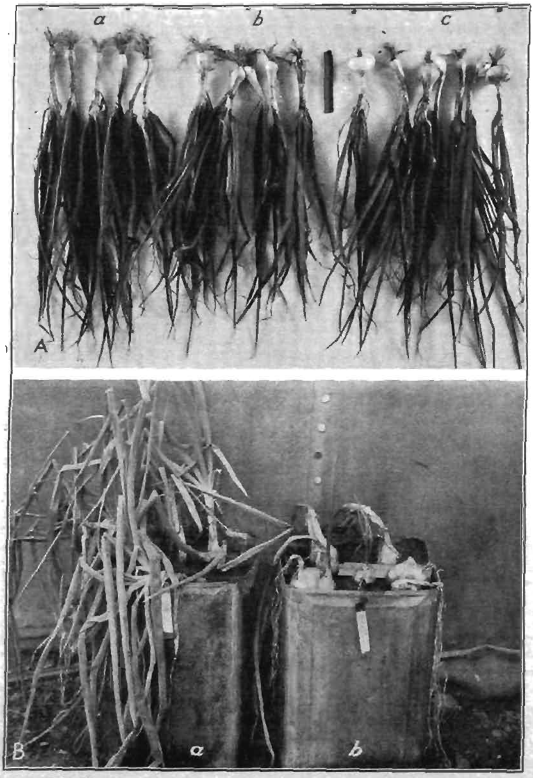

FIG. 8.—Silver King (Giant White Tripoli) onions. A, Light exposures of *a*, 11 hours; *b*, normal; and *c*, 13½ hours. December 12 to June 5. B, Light exposures of *a*, 10, and *b*, 15 hours. January 7 to July 28

Under a 15-hour daily light exposure, 2 of 5 plants showed bulbs half-developed at 20 weeks. At 22 weeks the tops of these 2 were over.

bulbs and the tops of 3 had died. Shortly after, new leaf growth started from 2 bulbs. Figure 8, B, shows their condition in the twenty-ninth week. At 35 weeks, 6 of the 8 bulbs which had developed from the 5 original plants had vigorously growing new tops. At 55 weeks, 2 bulbs had rotted, but 14 individuals, 2 of which were compound, had arisen from the other 6. All were at this time in the spring-onion stage.

As was the case with the varieties which were previously discussed, no correlation between splitting and length of daily light exposure was seen. Some splitting occurred in every planting under every exposure.

Onion Sets

The four onion varieties were grown in garden plots under normal light exposure and under a 15-hour daily light exposure. Seeds were planted February 10 in flats under normal light exposure and the resulting seedlings were set in the two groups April 4 and 5. They were removed June 3. During the time the seedlings were in the field the hours between sunrise and sunset ranged from 12.3 to 13.2. The size attained by the onions was small, the development being that of sets rather than anything larger, but the form stood in interesting relation to the daily light period. This is shown in Table 3.

Table 3.—*Effect of normal (12.3 to 13.2 hours) and 15-hour daily light exposures on onions grown in a garden for two months*

Variety of onion and length of daily light exposure	Number of plants	Percentage of total number of plants with—				Ratio of weight of bulb or basal 3 cm. of pseudo-stem to weight of growth above
		Tops green			Tops dead or dying	
		Pseudo-stems slender	Pseudo-stems with intermediate swelling	Bulbs	Bulbs	
Prizetaker:						
15 hours	85	89	5	6	0	1 : 3.01
Normal	166	100	0	0	0	1 : 4.22
Bermuda White:						
15 hours	90	1	0	10	89	1 : 0.02
Normal	119	7	10	34	49	1 : 0.28
Yellow Globe Danvers:						
15 hours	75	79	13	5	3	1 : 2.41
Normal	118	100	0	0	0	1 : 4.56
Silver King (Giant White Tripoli):						
15 hours	62	57	8	16	19	1 : 1.49
Normal	87	84	11	5	0	1 : 2.69

In all the varieties the growth of tops was proportionally much greater under the normal than under the longer light exposure. The tendency toward bulb development was greater under the longer exposure, two varieties showing no tendency in this direction under the normal exposure.

POTATOES

The potato as a crop is not generally grown in Porto Rico. Occasional plantings in the hills are reported as highly successful, but the coastal plain plantings of which the writer has been cognizant have resulted mainly in crop failures.

Three varieties of potatoes, Irish Cobbler, Red Bliss, and Lookout Mountain, were planted in containers under daily light exposures of 10 and 15 hours, and in the garden. Various interfering factors eliminated the garden check. However, within three days of planting the lighted garden plot, the rows were continued for a distance of 21 to 23 feet beyond, but were not screened from the lighted plot. This continuation of the rows, not originally intended as a check, became the only check available.

The potatoes were planted in the containers January 7 and in the garden January 5 to 8. Whole tubers selected for uniformity were used, except in the continuation rows. As one or more tubers of Irish Cobbler and Lookout Mountain had failed to sprout in the containers, the tubers of these varieties were replaced at one month after planting by sprouting tubers of the same from the garden.

The Irish Cobbler plants in the containers under the 10 and the 15 hour exposures showed little difference in height up to March 12, measuring, respectively, 17 and 18 inches. Further stem elongation soon ceased under the shorter, but continued under the longer light exposure, the plants measuring, respectively, 18 and 29 inches in height April 16.

The Red Bliss, as early as seven weeks after planting, was much taller under the 15-hour than under the 10-hour exposure. The ultimate heights attained were 16 and 30 inches under the short and long exposures, respectively. The Lookout Mountain plants which February 19 measured 1 and 3 inches in height, April 16 measured 19 and 60 inches in height, under the short and long exposures, respectively. These plants were photographed April 9. (Fig. 9, A.) Buds were noted on both plants March 8, and the first blossom opened March 16 to 19.

The plants were removed April 22. Whereas all tops were green and vigorous under the longer light exposure, those of Irish Cobbler and Red Bliss had died under the shorter exposure. At this time the weight of tops under the shorter exposure was only one-sixth to one-eleventh of that under the longer exposure. The Red Bliss showed little difference in tuber formation under the two exposures, Irish Cobbler showed some difference, and Lookout Mountain a pronounced difference. The ratio of the weight of the Lookout Mountain tubers, exclusive of seed tuber, under the shorter exposure to the weight under the long exposure was as 7 to 1. (Fig. 9, B.) While the ratio of new tubers to tops was as 2 to 1 under the 10-hour exposure, it was as 1 to 23 under the 15-hour exposure. Table 4 shows the weights of tops and tubers on removal, exclusive of the tuber planted.

TABLE 4.—*Weights of tops and tubers of three varieties of potatoes which were grown under daily light exposures of 10 and 15 hours' duration*

Length of daily light exposure	Weight of Irish Cobbler		Weight of Red Bliss		Weight of Lookout Mountain	
	Tops	Tubers	Tops	Tubers	Tops	Tubers
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
10 hours	39	243	23	309	78	158
15 hours	237	190	252	321	506	22

The potatoes grown in the garden were dug April 23 to May 4. Twenty-one to twenty-six plants of each variety were grown under the lights. Although there was no satisfactory check plot, the potatoes that were grown in the extension of the rows outside the area overhung by the electric lights bore a very interesting relation to their position with respect to the lights. The rows, extending to a

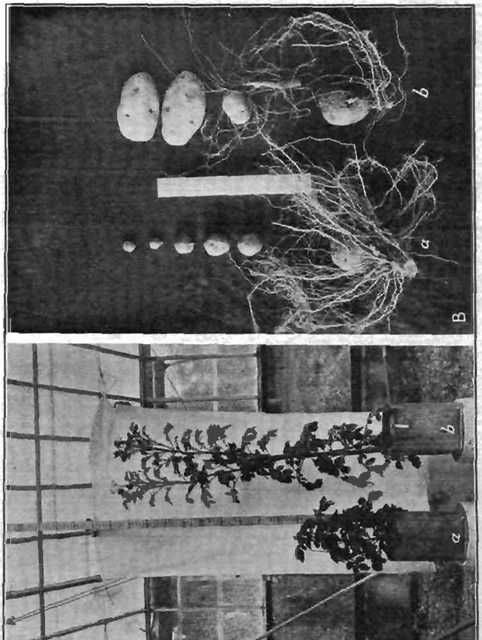

FIG. 9.—A, Lookout Mountain potatoes grown under daily light exposure of *a*, 10, and *b*, 15 hours; January 7 to April 9. B, *a* and *b*, Underground development of the potato plants shown in A; removed from the ground April 23

distance of 21 to 23 feet outside the lighted plot, were trisected, and plants nearest, midway distant, and farthest from the lights were weighed separately, 6 to 14 plants of each variety in each outside subdivision. Of each variety the plants which were grown under the lights showed the greatest leaf growth and the least tuberization. As was true for the plants grown in the containers, the differences within the variety were greatest in the case of Lookout Mountain, and least

in the case of Red Bliss. The plants of the Lookout Mountain and Irish Cobbler varieties outside the lighted area showed a tuberization correlated with their degree of proximity to the lights, those farthest removed showing heaviest tuberization.

Table 5 gives the average weight of potato tubers per plant from plants grown under a daily light exposure of 15 hours, and from plants grown in the same rows extended 21 to 23 feet beyond the area overhung by the lights.

TABLE 5.—*Average weight of potato tubers per plant from plants which were grown under a daily light exposure of 15 hours, and from plants which were grown in the same rows extended 21 to 23 feet outside the lighted area*

Location of plants	Average weight per plant of—		
	Lookout Mountain tubers	Irish Cobbler tubers	Red Bliss tubers
	Ounces	*Ounces*	*Ounces*
Within the lighted area	0.5	2.9	5.8
Outside of, but nearest to, the lighted area	1.9	3.4	7.5
Outside of, and farther removed from, the lighted area	3.1	4.8	7.0
Outside of, and farthest removed from, the lighted area	4.8	5.1	7.1

Of 24 plants of Lookout Mountain that were grown under the lights, 11 produced no tubers, and 5 produced tubers only about the size of marbles, or smaller; of 12 plants that were grown in the outside section adjacent to the lights, 3 produced no tubers, and 3 produced tubers only about as large as marbles; of 20 plants in the two sections midway distant and farthest removed from the lights, a single plant produced tubers only the size of marbles, and the other 19 plants produced 1 or more tubers of fair size. Similarly with Irish Cobbler, but in less pronounced degree, of 21 lighted plants, 3 produced no tubers, and 1 produced tubers only as large as marbles; in the adjacent section, 2 of 12 plants produced no tubers; whereas each of 23 plants in the two remaining sections produced 1 or more tubers of fair size.

CORN

Seed of Porto Rican corn, typical of that grown in the Yauco district, was planted January 26, 1927, in the garden plots under normal and 15-hour light exposures. In each plot two rows were planted 30 inches apart, and the plats were later thinned to about 12 inches apart in the row, the plot which received added illumination containing 44 plants, and the check plot 52 plants.

On March 12 the plants under the longer light exposure stood about 3 feet high and the check plants 2½ to 3 feet high. A week later the height from the ground to the highest leaf on any individual measured 68 inches in each group. On March 26 the lighted plants on the whole stood taller than the check. From this time on the difference in height of the two groups became increasingly pronounced. Their development on April 12, 76 days after planting, is shown in Figure 10, A and B. The average height of the lighted plants was 132 inches, and that of the check was 98 inches May 13 and 14, a few days prior to the removal of the check. The seven tallest plants in each group averaged in height 158 and 121 inches, respectively.

The number of nodes per plant was counted in an entire row in each plot—half the plants. Under the lengthened light period an

FIG. 10.—A, Porto Rican corn. Normal light exposure (11.3 to 12.5 hours); January 26 to April 12. B, Daily light exposure of 15 hours; January 26 to April 12

average of 21 nodes per plant was produced, whereas under the normal light exposure but 13.1 nodes developed. A count was made of the

number of nodes, visible without disturbing the soil, from which roots had started. The average was 3.6 nodes for the lighted plants, and only 1.2 nodes for the check. In the former group, only 1 plant failed to have a single node showing roots, whereas in the latter group 11 such plants were found.

On removal, the stalks were cut at the surface of the soil and weighed after the ears were taken off. The average weight per plant of stalk and leaves from the lighted plot was 2.6 pounds, whereas that from the check was only 1.1 pounds.

Differences in fruiting, as well as in vegetative development were very marked between the two groups. Staminate flowers were first noted on the check plants on March 26, when 5 tassels appeared, and the first silks in the same group were seen two days later. By March 31, more than half the check plants had tasseled and a quarter were with silks exposed. The lighted plants when examined April 11 as yet showed no tassels, but on the day following four were showing. At this time all the normally developed plants in the check, 48 of a total of 52, had developed tassels, and 46 of these had normal ears and were silking. By April 18, only 13 of the 44 plants receiving added illumination had developed tassels, a stage which had been reached by the check plants approximately three weeks earlier.

As the two rows of corn in the electrically lighted plot stood under the outer row of electric lights, the inner corn row received a stronger illumination than did the outer row. On April 23, 17 of 21 plants had tasseled in the outer row, whereas only 10 of 23 had tasseled in the better-illuminated row. Of the 21 outer-row plants, all but 3 showed either silks or small ears, whereas of the inner-row plants a single small ear without silks exposed was as yet evident. Examined again May 3, more than one-third of the plants in the better-illuminated row showed no indication of ears forming. This row was at this time not as advanced in the reproductive stage as had been the more dimly illuminated row 10 days previously. All but 4 plants had at least rudimentary ears forming by May 14.

The height at which the ears were produced on the stalks of the lighted plants was very noticeable. Whereas in the check the number of nodes to the lowest developed ear averaged 6.4, the average for the lighted plants was 11.8 nodes. The relative position of the ear in respect to the total number of nodes produced, however, did not differ greatly between the two groups.

The corn under the normal light exposure was harvested May 19, 113 days after planting. That grown under the lengthened light exposure was harvested June 8, 20 days later, the lighting having been discontinued June 3. The lighted corn was left in the field for this additional time in order to approximate as closely as possible in the two lots the same stage of maturity at removal. The ears in the husks were weighed immediately, those from the 52 check plants weighing 36 pounds 12 ounces, and those from the 44 lighted plants 25 pounds 13 ounces, which was an average weight per plant of 11 and 9 ounces, respectively. The ratio of the weight of ears and husks to that of stalks and leaves was as 1 to 1.6 for the check plants, and 1 to 4.5 for the lighted plants.

At 35 and 36 days after harvesting, the well-dried ears were graded as uniformly as possible and weighed. As the check plot was some-

what larger than the lighted plot the data were averaged per plant. Table 6 gives the production of Porto Rican corn under normal and 15-hour daily light exposures.

TABLE 6.—*Production of Porto Rican corn under normal and 15-hour daily light exposures*

Classification of ears	Average measurements per ear				Average production per plant			
	Length under normal daily light exposure	Diameter under normal daily light exposure	Length under 15-hour exposure	Diameter under 15-hour exposure	Number of ears under normal daily light exposure	Weight under normal daily light exposure	Number of ears under 15-hour exposure	Weight under 15-hour exposure
	Inches	*Inches*	*Inches*	*Inches*		*Ounces*		*Ounces*
First grade, largest and best	8.3	1.9	8.0	1.8	0.38	3.1	0.25	1.6
Second grade, well-filled, second best	7.2	1.8	7.1	1.6	.29	1.4	.14	.5
Third grade, short well-filled to longer mostly well-filled	6.3	1.6	6.3	1.5	.17	.7	.30	.9
Fourth grade, shorter well-filled to longer poorly filled	4.9	1.3	4.7	1.2	.19	.2	.16	.2
Total					1.03	5.4	.85	3.2
Fifth grade, cobs with only a few well-developed seeds					.15	.1	.27	.1
Sixth grade, short cobs with only a few poorly developed seeds					.23	.02	.14	.02
Seventh grade, rudimentary ears and cobs without any developed seeds					.73	.02	1.00	.05
Husks						.9		.7

The measurements in Table 6 show that the production of first-grade ears by the average plant was greater under normal light exposure than under a 15-hour exposure. Moreover, the first-grade ears, though more in number, were also longer and broader under the normal exposure. The same was true in the case of the second-best ears. The combined weight of the two grades under the normal light exposure was more than twice that under the 15-hour exposure. The total production also was considerably greater under normal light exposure than with the added hours of illumination. Whereas the longer light exposure favored vegetative development, the shorter exposure favored fruiting.

PINEAPPLES

Pineapples of the Red Spanish variety were placed August 8, 1925, under the 11-hour, normal, and 13½-hour daily light exposures. Thirty vigorous slips, weighing after stripping 140 to 206 gm. each, after being placed in sequence as to weight were divided into three groups by selecting alternating plants. The groups thus formed varied in weight of average plant by less than 4 gm. The 5-gallon tin containers were filled with river gravel to within an inch of the top, the larger stones having been previously removed from the gravel by screening. Suitable fertilizer in solution was supplied uniformly to all containers, first at weekly and later at longer intervals.

The lights were as for the miscellaneous plants until May, 1927, when an additional lamp was supplied to the pineapples, owing to the shading of the lower leaves by the leaves above.

Insect damage in the heart of two plants, one in the check and the other in the long-day group, necessitated their exclusion from the comparative data.

Measurements of the longest leaf on each plant showed an average difference of 1 inch at 6 months. The range in length of longest leaf

per plant at 9 months was 43½ to 53 inches, but the averages for the three groups were 48 to 49.6 inches, thus showing no material difference.

The first indications of the approach of blossoming were noted in May in the short and the normal day groups. The first plant to open flowers in the normal-day group blossomed May 22 and the second plant June 2. In the short-day group, two plants opened their first flowers June 15. No indication of blossoming was noted on plants under the longer daily light exposure until July 7. The first blossom in this group opened July 23. Prior to this time five plants in the short-day group and two in the normal-day group had finished flowering.

The fruits were picked as soon as they were considered to be fully ripe. In September, two in the short-day and two in the normal-day groups were picked, and in the short-day group three were picked in October, whereas in the long-day group the first fruit was picked November 1. The uniform fruiting and the vigorous condition of the plants of the latter group are shown in Figure 11, A, made shortly before the first fruit was picked. Whereas for the short-day group the mean fruiting date was October 24, for the check it was November 19, 26 days later, and for the long-day group December 1, 38 days later than for the short-day group. The difference between the groups in length of interim from the opening of the first blossom on a plant to the picking of the fruit was not pronounced, the season of blossoming being the main factor in determining the season of ripening. The data on production under the different length light exposures are given in Table 7.

TABLE 7.—*Red Spanish pineapple production under daily light exposures of different lengths*

Crop and length of daily light exposure	Mean ripening date [a]	Difference in mean ripening date of contemporary group receiving shortest daily light exposure and those receiving longer daily light exposures	Average length of time from blossoming to picking	Weight of average fruit	Weight expressed in percentage of weight of average fruit grown under shortest contemporary light exposure	Length of average fruit	Breadth of average fruit	Height of crown	Average number of crown slips per fruit	Average number of slips produced at base of fruit
From original plants:		*Days*	*Days*	*Grams*	*P. ct.*	*Inches*	*Inches*	*Inches*		
11 hours	Oct. 24, 1926	--------	96	1,605	100	5.8	5.2	10.0	0.4	1.8
Normal	Nov. 19, 1926	26	93	1,660	103	6.2	5.3	8.8	.8	2.3
13½ hours	Dec. 1, 1926	38	99	1,990	124	6.6	5.7	9.5	.2	4.3
From suckers:										
10 hours	Sept. 12, 1927	--------	100	1,085	100	5.1	4.8	8.6	0	.3
Normal	Oct. 3, 1927	21	100	1,177	108	5.2	4.9	9.4	0	.7
15 hours	Nov. 9, 1927	58	105	1,340	124	5.4	5.1	9.6	0	1.5

[a] Because of mechanical injuries, 1 or 2 fruits in each group of the second crop were picked prior to the normal ripening date. For each of these the normal ripening date, in order to obtain the mean, was calculated from its date of blossoming and the average number of days between blossoming and picking for the others of its group. One of these fruits had to be excluded in obtaining average weight and dimensions because of injury when immature.

Under the longer light exposure the fruits were both longer and broader, averaging 24 per cent heavier than under the short exposure, the check fruits being intermediate in size. Six of nine fruits pro-

FIG. 11.—Red Spanish pineapples. A, Daily light exposure of 13½ hours; August 8, 1925, to October 30, 1926. B, Light exposures of *a*, 10, and *b*, 15 hours

duced under the long-light exposure surpassed in weight the largest fruit produced in either of the other groups.

The difference in the number of slips produced was also notice-

light exposure, only 2.2 slips per fruit developed under the short exposure. As was the case in the size of fruit, the production of slips under the normal daily light exposure was intermediate between that of the other two groups.

In December a decided contrast was noted in the appearance of the plants in the different groups. Whereas in the normal and the short-day groups the lower leaves were yellowing, drooping, and dying, similarly located leaves in the long-day group were in the main green and turgid. And again later from time to time the much greener condition of the old pines under the long exposure was observed.

A change in the lighting period was made December 15, 1926. Although at this time two fruits remained to be picked in the long-day group, their development was too far advanced to have been materially affected by the change. Beginning at this date the lights were turned off at 15 hours after sunrise, and the plants in the short-day group were removed from the dark room at 10 hours before sunset, thus increasing the lighted period for the long-day group by 1½ hours, and shortening it for the short-day group by 1 hour. All slips were removed from the plants which had fruited, and the remaining slips were removed on picking the two remaining fruits. In each group one plant had developed two suckers, and the remaining plants one sucker each. These were left untouched.

The crop from suckers was produced considerably earlier than that from the original planting. The differences between groups in ripening season were more pronounced. The mean ripening date for the normal day group was 21 days later, and for the long-day group 58 days later than for the short-day group. (See Table 7.) The differences in stage of development June 10, 1927, are shown in Figure 11, B. The large fruits and the drooping, shrunken older leaves in the short-day group contrast strongly with the turgid older leaves and the almost total absence of fruits in the long-day group. One of the latter had blossomed at this time and three were showing buds, thus as a group just entering the blossoming stage. As was the case in the preceding crop, the difference in dates of ripening was due mainly to a difference in the blossoming dates rather than a pronounced difference in time required to mature, though this averaged slightly longer under the longer daily light exposure.

The blossoming of the group as a whole, and consequently the ripening season, of both the original and sucker plants was spread over a longer period under the normal light exposure than under either the short or long daily light exposures.

The fruits produced by the suckers, more poorly conditioned than the original plants, were smaller, but bore the same group relations. Seven of the 10 fruits produced under the long exposure surpassed in weight the largest fruit produced under the short exposure. An eighth fruit which weighed only 6 gm. less than the latter would doubtless have weighed much more had not the sucker on which it was borne fallen over more than two months prior to the ripening of the fruit, half breaking through at the base. The average fruit produced under the 15-hour daily light exposure weighed 24 per cent more than that produced under the 10-hour daily light exposure,

was both longer and broader, and was subtended by a greater number of slips. Only a single fruit produced under the normal light exposure attained the weight of the average fruit produced under the 15-hour daily light exposures.

On March 7, 1928, the plants were cut at the surface of the soil, and the growth above ground was weighed. The average weight per container was 6.8 pounds under the 10-hour exposure, 7.7 pounds under the normal exposure, and 8.2 pounds under the 15-hour daily light exposure, the latter being 21 per cent greater than that under the 10-hour exposure. The weights under the 10-hour and normal exposures included some immature fruit without which the averages would have been reduced by 0.1 pound and 0.3 pound, respectively. Whereas on removal of the plants, 5 under the 10-hour exposure, and 6 under the normal exposure, carried buds, flowers, or young fruit, only 1 under the 15-hour daily light exposure had as yet budded, thus in the third crop showing retarded flowering under the lengthened period of illumination.

BEANS

Three varieties of beans were grown, two of which are the most common locally, a white and a red, the latter a plump mottled bean sometimes designated Guayamera, and a continental variety, Red Valentine. These will be referred to as White, Red, and Valentine.

From March 11, 1924, to June 30, 1925, 18 plantings were made at intervals of four weeks and later 2 additional plantings were made. The containers used were 5-gallon tin cans, each carrying river loam in amount equivalent to 50 pounds of moisture-free soil which previously was screened and well mixed. Owing to the unsatisfactory growth made in the first 9 plantings, fertilizer in suitable amount and quality was supplied thereafter. In the first 7 plantings 10 plants were grown in each can, and thereafter only 5 plants. Nematodes, insects, and diseases proved to be troublesome at times, and together with atmospheric variations caused widely different growth and production in plantings made on different dates. In some instances one or another of these disturbing factors interfered with normal growth to such an extent as to make it advisable to omit certain plantings in obtaining the averages presented in Table 8.

TABLE 8.—*Growth, blossoming, and production of three bean varieties under 11-hour, normal, and 13½-hour daily light exposures*

Variety and length of daily light exposure	Interval between planting and blossoming	Interval between blossoming and ripening of crop	Interval between planting and death of vines	Height of plant	Number of pods per plant	Weight of dry seed per plant
	Days	*Days*	*Days*	*Inches*		*Grams*
White:						
11 hours	40	32	80	19.0	3.4	2.4
Normal	41	31	84	19.8	4.1	2.8
13½ hours	42	32	90	27.6	3.9	2.9
Red:						
11 hours	30	32	77	10.5	2.3	1.3
Normal	30	32	77	9.9	2.4	1.4
13½ hours	30	32	84	12.3	2.1	1.2
Valentine:						
11 hours	33	35	67	11.7	2.5	1.2
Normal	33	35	71	10.6	3.0	1.2
13½ hours	32	34	72	13.6	2.4	1.0

The day on which the second plant to blossom opened its first flower was considered as the blossoming date for each group. No pronounced effect in hastening or retarding blossoming resulted from the difference in length of daily light exposure. In 18 plantings of the White bean the long-day group blossomed later than the short-day group in 11, contemporaneously with it in 2, and ahead of it in 5 plantings. On the whole, the long-day group averaged 2 days later than the short-day group in coming into blossom. On the other hand, the Valentine bean under the long daily light exposure blossomed on an average 1 day earlier than in the other two groups. The average of 20 plantings of the Red bean was the same under each of the three different light exposures. The extremes were 27 and 33 days and occurred in both the short and the long-day groups.

The interval between the date of blossoming and the date of ripening of the first pods on two plants was considered as representative of the length of time required for maturing pods. There was not evident in any variety any material difference in time required for ripening under the different daily light exposures as averaged from data on 12 or more plantings of each.

The relation between yield and length of daily light exposure was too inconstant to furnish conclusive evidence. In 19 plantings of the White bean, the long-day group surpassed in weight of crop the normal-day group 11 times and the short-day group 13 times. The difference in yield of plantings made on different dates but given the same daily light exposure was often greater than that of groups receiving different light exposures but planted contemporaneously. The production curves of the White bean under the three different light exposures follow the same general trend and show that other factors affected production to a greater extent than did the length of daily light exposure, veiling this effect in large measure. Whereas the White bean was on the whole less productive under the short daily light exposures, the Red and Valentine beans were slightly less productive under the long exposure. In average weight of dry seed per plant, the Red bean under the short exposure surpassed that under the long exposure in 13, equaled it in 1, and fell below it in 6 plantings.

While the height curves show in like manner a wide variation between plantings made on different dates, the favorable effect of long daily light exposures remains clearly evident. (Fig. 12.)

The height of each plant was recorded. In 18 of 20 plantings of the White bean the group receiving the longer exposure surpassed both other groups in height. Of the 20 plantings, as a whole, the average plant in the long-day group measured 39 per cent taller than in the check, and 45 per cent taller than in the short-day group. A comparison of the long and the short day groups of the Red bean showed that while the difference in height was less pronounced, the effect of the longer daily illumination was no less evident than in the preceding variety. In only a single one of the 20 plantings was the long-day group surpassed in height by either the short-day group or the check. In 15 plantings of Valentine beans, the long-day group surpassed the check in height in every planting and the short-day group in 10 plantings.

The length of life of the plant was reckoned from the date of planting to the date on which the plant neither carried live leaves nor was putting out new growth. The individual life span was recorded in all plantings after the seventh. The long-day group exceeded in average length of life the normal-day group in 9, and the short-day group in 8, of 13 plantings of White beans. The average length of life under the short, normal, and long daily light exposures was 81, 84, and 91 days, respectively. Similarly, the average length of life of the Red bean was 84 days under the long daily light exposure, and 77 days in the other two groups; and that of the Valentine bean was 67, 71, and 72 days for the short, normal, and long day groups, respectively.

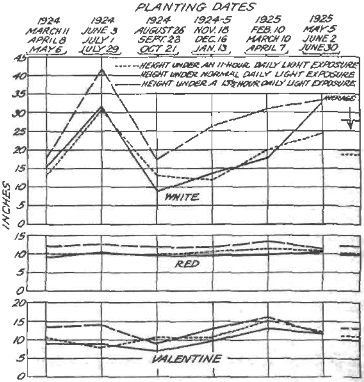

FIG. 12.—Height of bean plants as affected by difference in length of daily light exposure [1]

DISCUSSION AND SUMMARY

Economic plants of different varieties were grown under daily light exposures of 10, 11, 13½, and 15 hours, and under the normal light exposure, 11 to 13.2 hours (sunrise to sunset).

An 11-hour daily light exposure proved to be more favorable to the blossoming of both Porto Rico and Key West sweet potatoes than a 13½-hour exposure. The evidence as to the effect of these light exposures on vine growth and tuber formation was inconclusive.

The growth of the different onion varieties under the varied light exposures showed onions to be very sensitive to the duration of the daily light period. Different varieties varied in their responses to different day lengths. An exposure sufficient in length to cause bulb formation in one variety may be wholly inadequate in the case of another. For this reason, certain varieties which form large bulbs in temperate latitudes may fail wholly to form bulbs when grown in the Tropics. In the lower latitudes where the temperature permits planting throughout the year, not only is it essential to select such varieties as will form bulbs under the day lengths which prevail in these latitudes, but the favorable planting time as well must be determined with regard to the seasonal day length. While the shorter days favor leaf growth, they inhibit bulb formation, for which the longer days are necessary. Of the four varieties included in these tests, one only, Bermuda White, showed itself to be well adapted for

[1] Each point determined by average height of 3 plantings, except Valentine second and fifth points determined by 2, and third point by 1 planting.

growing in such latitudes as have a maximum day length only shortly in excess of 13 hours. Though some individuals of the Silver King (Giant White Tripoli) variety formed bulbs, the varietal adaptability to such day lengths could be considered as only partial. The Prizetaker and Yellow Globe Danvers varieties are wholly unsuited for growing under such day lengths, plants in the main remaining in the spring-onion stage rather than forming bulbs. Under daily light exposures of a little more than 15 hours, normal bulb formation was rapid in all four varieties.

The tendency of the onion to form more than one core, or to split into two or more individuals was not shown to be correlated with the length of daily light exposure, but rather to be a varietal characteristic. This tendency was most pronounced in Bermuda White and Silver King (Giant White Tripoli), and least evident in Yellow Globe Danvers. Owing to vigorous top growth and absence of bulb formation under the shorter exposures, the splitting of one individual into several was more conspicuous under the shorter than under the longer daily light exposures where bulbs were quickly formed and the resting period was entered. On resumption of growth the compound formation of the bulb under the longer exposures became evident.

The Irish Cobbler, Red Bliss, and Lookout Mountain varieties of potato differed considerably in sensitiveness to differences in length of daily light exposure. Of the three the Lookout Mountain variety proved to be the most sensitive, and the Red Bliss the least so. Whereas the longer exposure favored growth of tops, the shorter exposure favored tuberization.

Porto Rican corn showed pronounced differences in growth and production under normal and 15-hour daily light exposures. Under the lengthened exposure blossoming was delayed, a much greater height was attained, and the production was inferior in number and size of ears to that under the normal light exposure.

Red Spanish pineapples were grown under normal, 10, 11, 13½, and 15-hour daily light exposures. Under the longer exposures blossoming was delayed, the size of the fruit was considerably larger, the production of slips was notably greater, and the total growth was increased.

The most clearly evident and consistent effect of the longer daily light exposure under which the beans were grown, 13½ hours, was the increased vegetative activity as shown by the greater height and greater length of life under the longer daily illumination.

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